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A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

THE FACTORS WHICH AFFECT THE ENERGY LOSSES IN ARMATURE CORES.

J. WALTER ESTERLINE AND C. E. REID.

The investigations which form the basis of this paper have been conducted at the Electrical Laboratory of Purdue University during the past two years. The purpose was primarily to develop an apparatus suitable for rapid yet accurate testing of sheet metal used in armature cores; secondary to this was the study of the effect of certain factors upon the energy losses which occur in the armature cores of generators and motors.

The Apparatus.

A general view of the apparatus is given in Fig. 1. The wrought iron field-ring is 14 inches in diameter, 3 inches in width, with an inner diameter of 10¾ inches. This yoke is provided with five sets of poles, as follows: (1) 2 poles, solid wrought-iron; (2), 4 poles, solid wrought iron; (3), 6 poles, solid wrought iron; (4), 8 poles, solid wrought iron; (5), 2 poles, built of .022 sheet steel. The poles are so dimensioned that 50% of the armature core is covered by each set. The field poles and exciting coils are shown in Fig. 2.

The apparatus was designed so that the specimens for test would be in the form of ordinary armature punchings, and the samples tested consisted of seven cores built up of sheet steel discs .015 inches thick. Fig. 3 is from a photograph of discs from the different cores. The outer diameter of these is six inches, while the inner diameters vary from 2 to 5 inches, in different cores. Four of the specimens tested have a smooth periphery, and three others, with corresponding inner diameters, are slotted. The slots in these cores are 48 in number and $\frac{5}{16}$ inches wide by ½ inch deep.

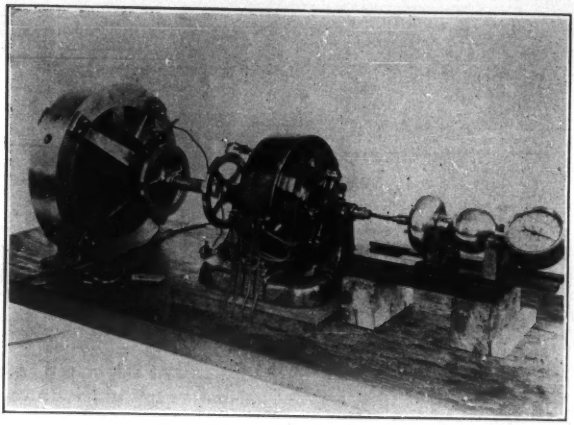


FIG. 1.

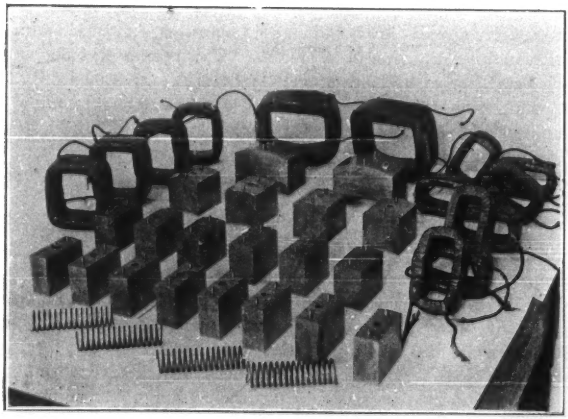


FIG. 2.

To insure a uniform quality of metal in all the cores, the discs were all stamped and then thoroughly shuffled, after which the holes were punched in the different lots. The slots were milled in the cores which were to be toothed, and all the discs were carefully annealed.

The punchings were given a coat of shellac and mounted on hardwood sleeves which fit a heavy steel shaft carried in bearings fastened directly to the field-ring.

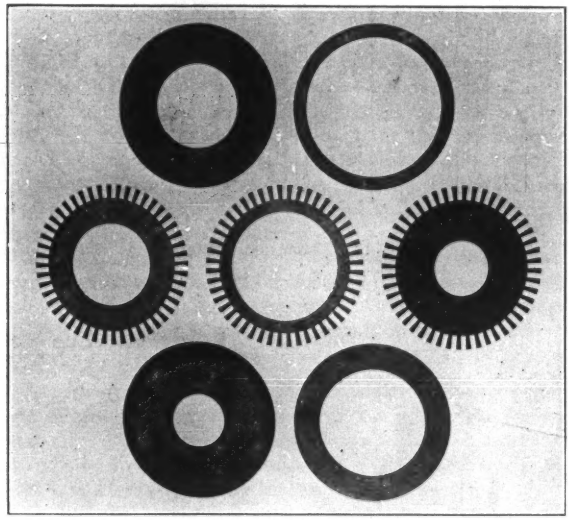


FIG. 3.

In order to insure a uniform density in the air gaps under the different poles, so that there would be no undue increase in the bearing friction when the fields are excited, and to insure an equal distribution of the flux in the core, the poles were bored while clamped in the field ring, the tool being carried on the shaft.

The shaft was driven by a small direct current motor through a modified form of the Goldsborough torsion dynamometer shown in Fig. 4*. The bearings which formed a part of the

* TRANS., A. I. E. E., 1900.

original type of dynamometer were discarded, one of the wheels was carried on the driving-end of the motor shaft and the driven member fitted to a quill which fits the shaft of the apparatus, permitting the removal of the latter without disturbing the adjustment of the dynamometer spring. The dynamometer was adjusted to the desired degree of sensitiveness by changing the size of spring used.

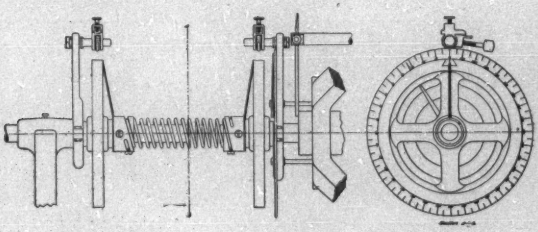


FIG. 4.—Dynamometer Details.

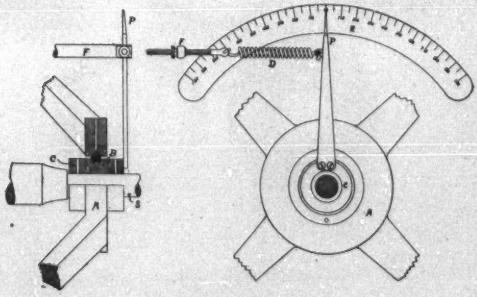


FIG. 5.—Bearing Details.

In order to detect and correct for any change of the bearing friction, should the armature become magnetically unbalanced, or the lubrication of the bearings imperfect, the bearings were made of special design, as shown in Fig. 5. The shaft s runs in the phosphor-bronze bearing c, which, instead of being fastened firmly to the arm A, is mounted in a ball bearing B. When the shaft is rotating, the friction tends to cause the bearing c to

rotate with the shaft, as the friction of the ball-bearing was found by test to be negligible in comparison with that of the plain bearing. Instead of allowing C to rotate, it is held by a spring D attached to an arm at P. At the beginning of a run the adjustment at F was made such that the pointer stood at O when the machine was running at the speed at which the test was to be run. Any increase in the friction of the bearings is measured by the movement of P in the direction of rotation, and the reverse for any decrease. The divisions on the scale E represent the number of degrees through which it is necessary to twist the dynamometer spring to produce the given deflection of the spring D, *i.e.*, 10 divisions on the scale E indicate that if the torque necessary to twist the dynamometer spring through 10 degrees be applied to the spring D, the pointer will indicate 10. Such a scale was calibrated for each of the two bearings for each of the dynamometer springs used, by clamping the bearing C to the shaft, and marking the position of P corresponding to the different angles through which the dynamometer spring was twisted in order to produce the deflection of D.

The driving-motor was operated separately-excited, and variable speed was obtained by changing the impressed e.m.f. of the armature. The speed was indicated by a Buss-Sombart tachometer attached to the armature shaft of the motor.

Purpose and Method of Tests.

The energy losses which attend the rotation of an armature core in the magnetic field consist of the bearing-friction and windage, hysteretic and eddy current loss in the core in the case of smooth cores, to which is added an eddy current loss in the pole faces when the cores are toothed.

As indicated in the following diagram, the hysteretic losses may be said to depend upon the quality of the iron, the frequency of the flux reversals and the maximum density reached during a cycle. The frequency is a function of the number of poles and the speed. The maximum magnetic density is dependent upon a number of conditions, and is usually different in different parts of the core at the same instant. The distribution of the magnetic flux through the core depends mainly upon the depth of the core, the number and pitch of the poles and the dimensions of the tooth and slot. The greater the radial depth of the core, the greater the difference between the maximum and minimum densities within the core, for a given average density, and as the depth of the core becomes less the distribution of the flux becomes more

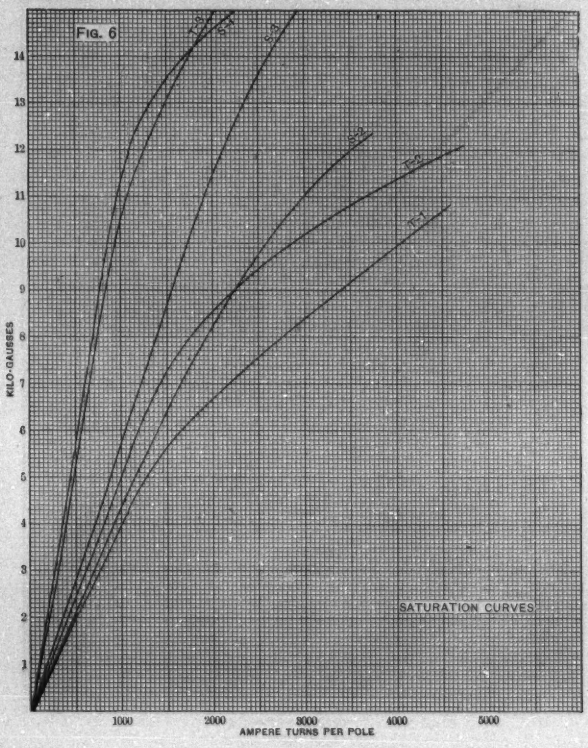
and more uniform. The cores of different internal diameters were tested to determine the effect of the variation in the flux distribution upon the core loss. The frequency and flux distribution both being dependent upon the number of poles in a machine, these cores were tested under different numbers of poles also.

When an armature core is slotted, the magnetic density in the teeth is greatly increased for a given air gap or core density, and the presence of teeth on the core is attended by an eddy current loss in the poles. The latter may be greatly reduced by laminating the poles, so that a comparison between tests of a toothed core under solid and laminated cores should indicate to what extent this loss in the pole faces may be reduced. The increase in the energy expended due to the higher densities in the teeth may be shown by comparing tests of smooth and toothed cores under well laminated poles.

- Total
  - Hysteretic loss.
    - Quality of iron.
    - Frequency.
      - No. of poles.
      - Rev. per second.
    - Max. Density.
      - Air gap flux per pole.
      - Cross section of core.
      - Distribution of Flux.
        - Depth of core.
        - No. of poles.
        - Dimensions of tooth and slot.
  - Eddy Currents
    - Core
      - Frequency.
      - Lamination.
      - Density.
    - Poles
      - Density.
      - Size of teeth and slots.
      - Air gap length.
      - Degree of lamination.

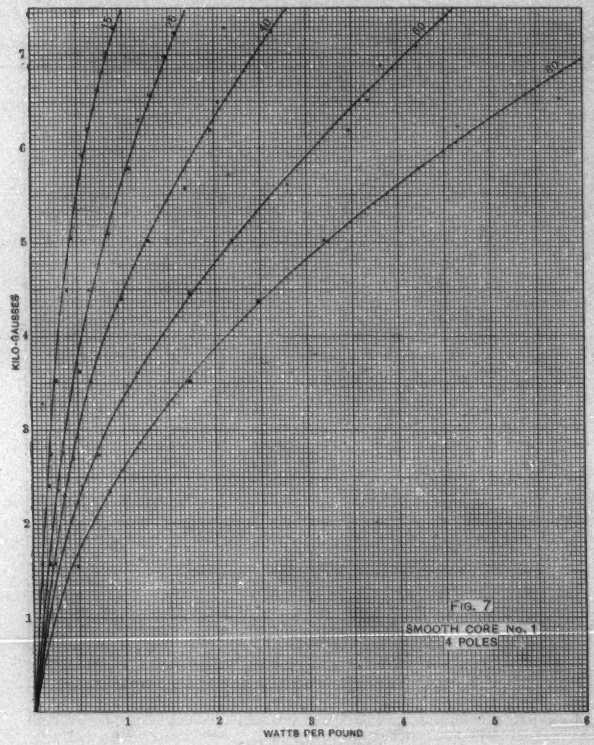
To make a core, enough discs of one kind were selected to give a gross length of 3 inches. These were weighed, given a coat of shellac and assembled. Before placing the core within the field an exploring coil was wound about the face of one of the poles and another wound so as to embrace the total flux passing through one section of the core. After placing the sample in the apparatus, a saturation curve was taken by means of a ballistic galvanometer in connection with the exploring coils just mentioned. These curves (Fig. 6), show the relation between ampere-turns per pole and average magnetic density in the core.

The field poles were next thoroughly demagnetized by an alternating current. On starting the motor, the dynamometer reading indicates the bearing friction and windage; the springs which hold the bearings were adjusted so that the reading of the pointers P, was zero.



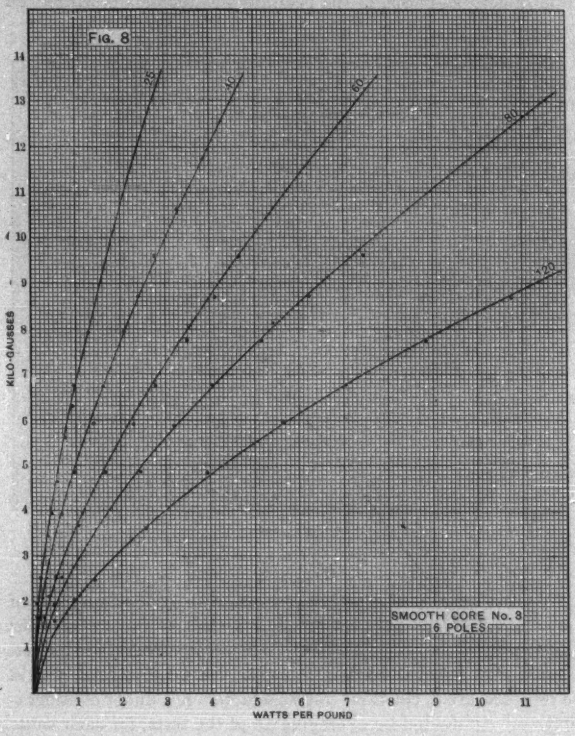
The speed being adjusted to give a desired frequency, it was held constant, and the exciting current varied stepwise, readings of current in the fields, dynamometer and scale for bearing friction, being taken simultaneously for each value of current. When maximum current was reached, the fields were again demag-

netized, the speed changed to give the next desired frequency, the bearing springs adjusted and the operation of varying the current repeated. Each core was tested in this manner under five sets of poles, at five different frequencies and varying magnetic densities, making 225 complete tests.



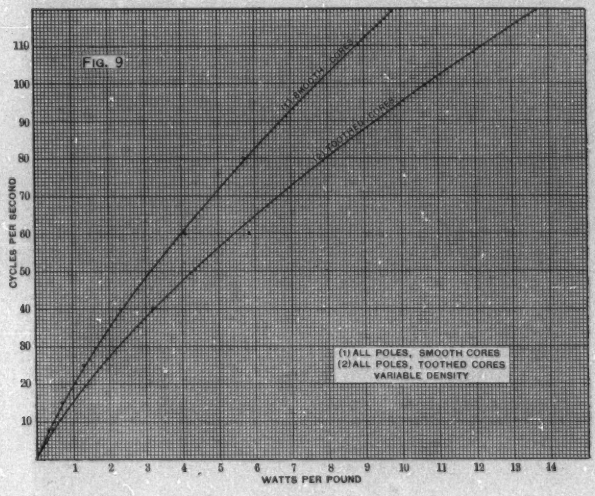
When the fields are excited, the power required to drive the core consists of the friction and windage and iron losses. The difference between the dynamometer reading for any current, and the friction reading, is the iron loss. If the pointers attached to the bearings indicate any change in the friction, the amount so indicated can be subtracted from or added to the original

friction reading, depending upon whether the friction has decreased or increased, since the scales E are graduated in degrees of the dynamometer spring. From the corrected dynamometer readings the watts core-loss in watts was determined, which divided by the weight of the core gives the watts per pound. Referring to the saturation curve, the densities in the core for



the different values of ampere-turns per pole are found, and curves plotted for each frequency, average density as ordinates, watts per pound abscissæ. The original curves from 2 of the 35 tests are shown in Figs. 7 and 8. The current in the exciting coils was taken from a storage battery and measured by a

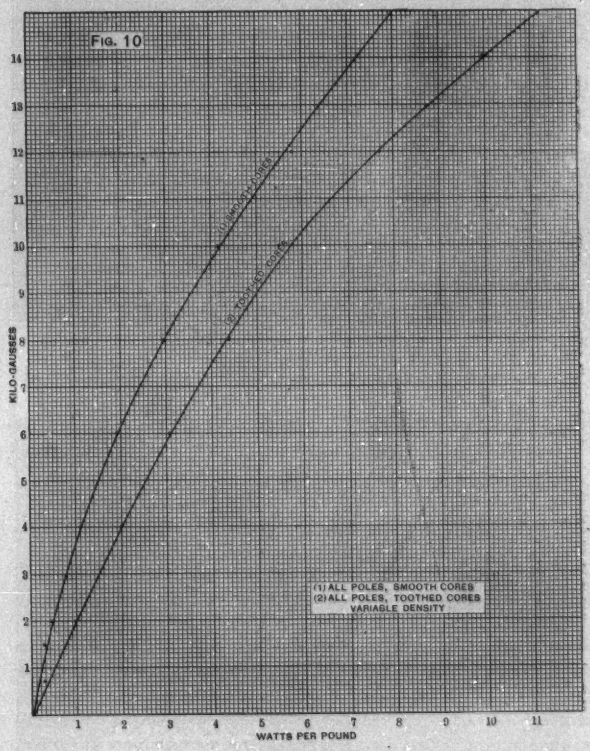
Weston laboratory standard ammeter. The dynamometer was frequently calibrated, and gave the same result each time. The centering of the cores in the bore of the poles was so successfully accomplished, that there was very little increase in the friction due to magnetic pull. So sensitive, however, were the ball bearing attachments, that the increase of friction due to a drop of cold oil in one of the bearings was readily shown by the pointer.



RESULTS.

To illustrate the relation between the core loss and any one of the four variables—frequency, magnetic density, number of poles and depth of core—curves have been drawn from data derived from the 35 original curves. In order that the results should be representative, the three variable factors not under consideration were eliminated by averaging all of the tests, for each value of the variable under consideration. For example, Curve No. 1, Fig. 9, exhibits the relation between the frequency in cycles per second and core loss in watts per pound, for all the cores having smooth periphery, under sets of 2, 4, 6 and 8 poles, and at magnetic densities ranging from 2,000 to 14,000 gausses, for each value of frequency.

Curve No. 2, in the same figure, shows a similar relation for all of the toothed cores. The curve for the cores having teeth shows considerably higher losses, due to the energy loss in the pole faces and the increased hysteresis loss resulting from the high magnetic density in the teeth of the core.



Curve No. 1, Fig. 10, gives the relative values of the core loss and maximum average magnetic density for all of the smooth core at frequencies ranging from 7.5 to 120 cycles per second. Curve No. 2 shows a similar relation for the toothed cores.

In studying the effect of variable numbers of poles and depth

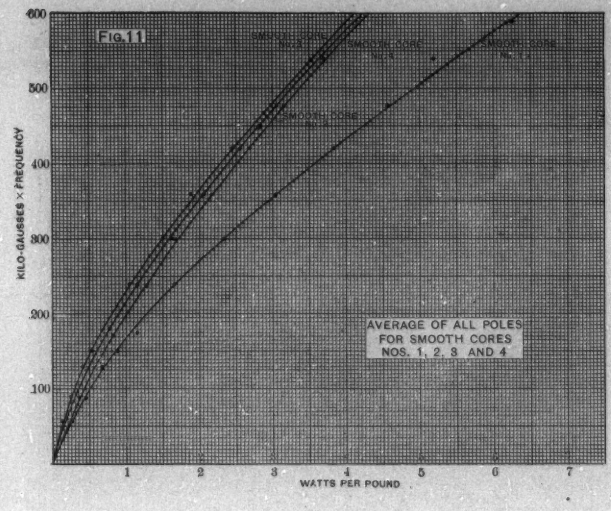


Fig. 11
KILO-GAUSSES × FREQUENCY
WATTS PER POUND
AVERAGE OF ALL POLES
FOR SMOOTH CORES
NOS. 1, 2, 3 AND 4

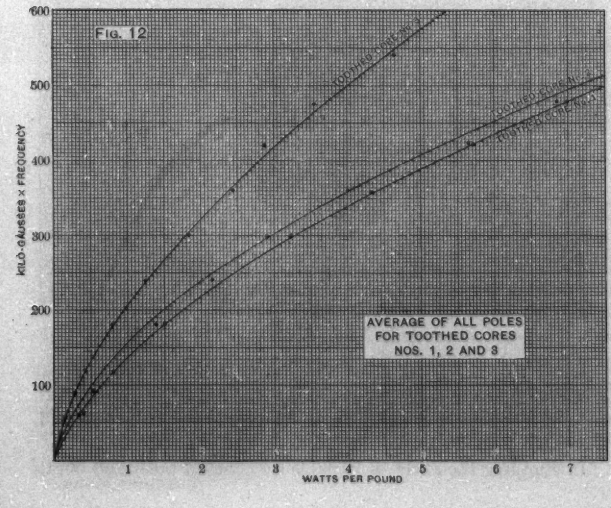
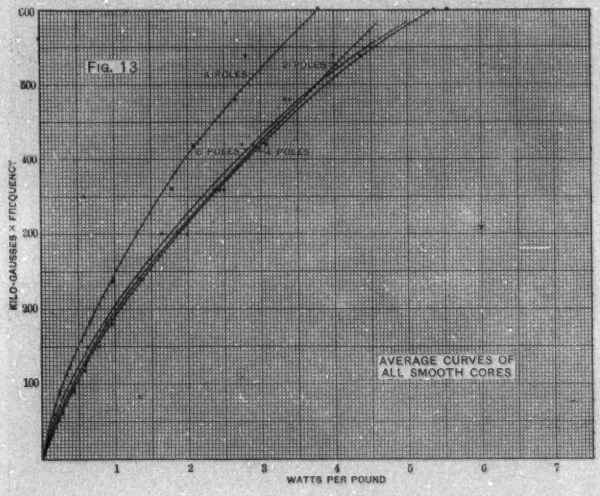


Fig. 12
KILO-GAUSSES × FREQUENCY
WATTS PER POUND
AVERAGE OF ALL POLES
FOR TOOTHED CORES
NOS. 1, 2 AND 3

of core, the product of the frequency and magnetic density was considered as a single variable. As shown in Fig. 11, the relatively shallow cores, in which the magnetic density is more nearly uniform, have the lowest values of core-loss for the same average magnetic density and frequency. The same is true for the toothed cores, as shown in Fig. 12. The lines of force in passing from pole to pole through the core, seek the path of least reluctance, and in so doing increase the density in the outer portions of the core. In Fig. 11, core No. 1 has a radial depth of 2 inches, No. 2, 1.5 inches, No. 3, 1 inch, No. 4, .5 inch. Of the



toothed cores, the results from which are given in Fig. 12, core No. 1 has a depth below the teeth of 1.5 inches, No. 2, 1 inch and No. 3, .5 inch.

Fig. 13 would indicate that there is practically little change in the core loss for different numbers of poles, for the same magnetic density and frequency, so far as the smooth cores are concerned. The curve for 8 poles differs from the other three on the same sheet, more probably due to the fact that it was impossible to obtain as high magnetic densities with these poles as with the others, but the frequencies obtained were of course somewhat

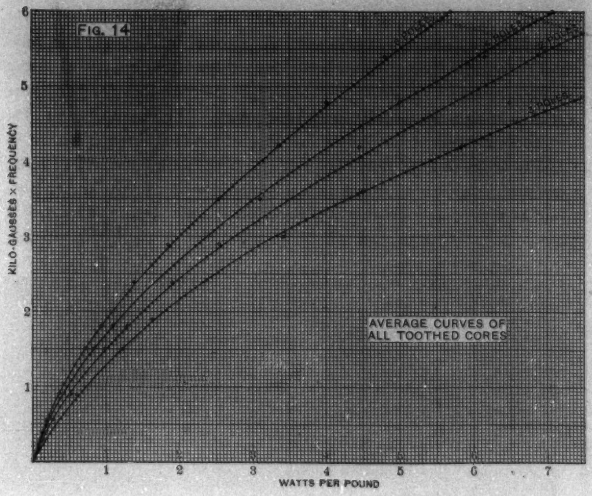


FIG. 14
KILO-GAUSSES × FREQUENCY
WATTS PER POUND
AVERAGE CURVES OF
ALL TOOTHED CORES
1
2
3
4
5
6
7

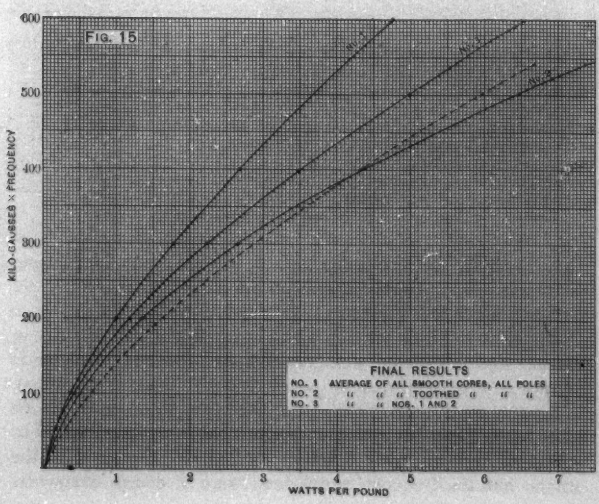
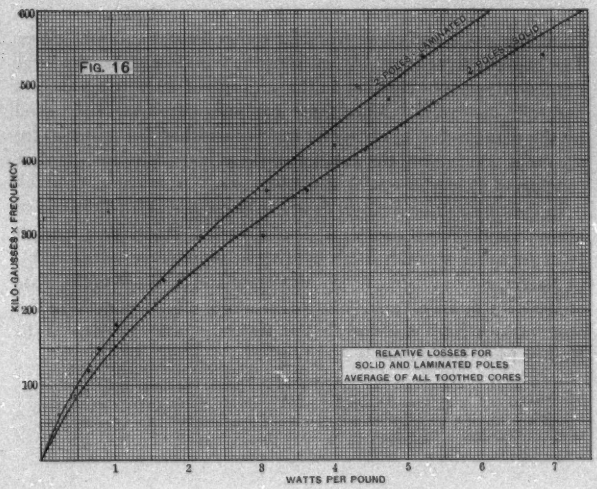


FIG. 15
KILO-GAUSSES × FREQUENCY
WATTS PER POUND
FINAL RESULTS
NO. 1 AVERAGE OF ALL SMOOTH CORES, ALL POLES
NO. 2 " " " TOOTHED " " "
NO. 3 " " NOS. 1 AND 2
100
200
300
400
500
600
1
2
3
4
5
6
7

higher. However, in the case of the toothed cores, as shown in Fig. 14, there is considerable variation in the core loss for different sets of poles, at the same frequency and density.

In Fig. 15 curve No. 1 is the average of the four curves shown in Fig. 13, and therefore is a summation of all data taken on the cores having smooth periphery. Curve No. 2 in the same figure is a similar deduction from all the data on the slotted cores. The increase in the loss of energy due to the slotting of the core is plainly set out, as shown by the difference of the values of the abscissæ of the curves 1 and 2. Curve No. 3 is a final average of



the results from all the smooth and all the toothed cores and is the result of some 12,000 observations.

Curve No. 1, Fig. 16, is the mean result of all the toothed cores tested under a pair of laminated poles, while Curve No. 2 in the same figure is the result of tests of the same cores under a pair of solid poles; the difference in the abscissæ of these two curves denoting the reduction of the eddy current loss in the poles due to lamination of the same. In building up the laminated poles, no effort was made to produce a laminated pole in any way superior to those obtained in commercial practice. After the poles were

built up, they were faced inside and out, in the lathe; and the tests conducted on the poles just as they came from the lathe, no attempt being made to remove the effects of the tool in forcing the plates together.

It will be noted in curve No. 1, Fig. 16, the toothed cores and laminated poles check fairly closely with curve No. 3 of Fig. 15, which is the average of the smooth and toothed cores under solid poles, and also that the difference between curve 2 and 3, Fig. 15, is very nearly equal to the difference between the curves in Fig. 16. This being the case, we should expect curve No. 1, Fig. 15, to be representative for smooth cores under either solid or laminated poles; curve No. 3 for toothed cores, with laminated poles and curve No. 2 for toothed cores and solid poles. The broken curve (Fig. 15), is from the core loss tests of a large number of machines having, in the majority of cases, toothed cores and solid cast poles. Since these machines were built and tested by the manufacturing company which furnished the material for the cores which were the subject of these investigations, the last conclusion at least seems justifiable.

In conclusion, the authors desire to express their obligations to Messrs. A. E. Wood and C. A. Davis, of the graduating class of 1902, for much assistance in preparing the apparatus and samples; to Messrs. R. E. Clisby, A. W. McHenry and J. W. Skinkle, class of 1903, Purdue University, for painstaking efforts in making the observations and calculating the results; also to Mr. A. L. Hadley for much valuable assistance.

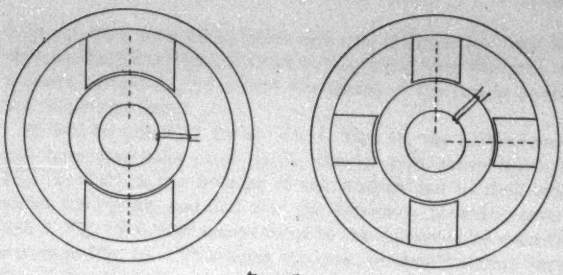
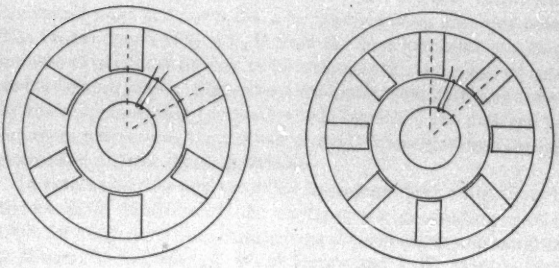


Fig E



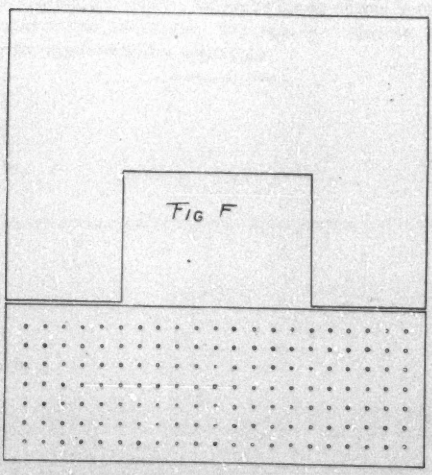


Fig F

DISCUSSION.

PROFESSOR ESTERLINE:—I might also call attention to the fact, which is not mentioned in the paper, that for each smooth core which was tested, there was a toothed core, the depth below the teeth corresponding exactly with the radial depth of the smooth core, so that the results from smooth and toothed cores were readily comparable.

PROFESSOR GOLDSBOROUGH:—Professor Esterline in his paper has given us only a small part of the results which he obtained in the course of the experiments, and I think that by reference to his curves we will all agree that some of them represent so many variables that it is somewhat difficult for us without some study and thought to appreciate exactly what they mean. On the other hand, after they have been analyzed they bring to us very much more definite information regarding certain points bearing upon the matter of losses in armature cores than we have ever before had. If you will notice, for instance in Fig. 14, we have a set of curves plotted with watt loss per pound as abscissas. and the product of the flux-density and frequency as ordinates, You will notice that the curve for eight poles falls below the other curves. In other words, we have the curve for two poles below that for four poles, and the curve for four poles below that for six poles. When it comes to eight poles the curve drops down below all the other curves. Now, it must be remembered that these poles are referred to the *same* field ring and the *same* armature cores; that is, at first two poles were used; then four poles were placed in the field rings; then these were removed and six poles were put in the same field ring and finally eight poles were put in. In each case the *same per cent. of the surface of the armature was covered by the poles*. The reason that the eight-pole curve falls low is owing to the fact that you have saturation in the armature core. For instance, take this to be the armature core (see Fig. E.) Here we have the field ring common for all of the cores (indicating on blackboard), and with the eight-pole machine we have the poles making angles of 45° with one another. Now, the densities, if I understand rightly, are taken in the neutral plane (indicating); that is, the density values represent the average densities across the core between the pole tips. We have, of course, a flow of flux from one pole over to the next one, and we get a certain point near the surface of the core where the flux is highly concentrated. As a general thing you will find that the iron at the surface of the core is very much more densely permeated with flux than that at the inner side. In some experiments I have made I found as many as 14,000 lines at the top and only 2,000 lines at the bottom. This is something that we frequently lose sight of—that there is so great a variation in the density between the inner and the outer edges of the lamihas.

In the case of the two-pole machine tested we get a greater variation in the core-flux distribution than we do in the case of

the four-pole machine. the density there probably being greatest near the *inner edges* of the laminas, owing to the small per cent. of the armature surface covered by the poles and to the fact that the poles are diametrically opposite one another with relatively low air-gap densities, as compared with the core densities between the poles. The six-pole machine gives still less variation; that is, we come to a point where the distance between the pole corners and the air-gap density is such that we get a fairly uniform distribution across the core. When we pass to the eight poles another condition arises. You will see, with the same amount of flux passing between poles, we get a relatively small density in the air-gap of the two-pole machine, by comparison with the others. When we increase the number to four poles the density in the air-gap gets higher. With six poles the density in the air-gap gets still higher. When we come to eight poles the density in the air gets very high, and the maximum loss instead of occurring in any section between the poles, now occurs in the iron immediately beneath the poles. In other words, for the eight-pole curve we have the greatest hysteresis loss occurring right underneath the pole tips, owing to the fact that saturation of the iron occurs immediately below the pole tips. In passing, then, from a two-pole curve up to six and back again to eight, we have passed through a cycle; a cycle in which we first have the greatest loss at points near the bottom of the core and between the two poles, and finally have the greatest loss at the surface of the core under the pole tips. These are matters in design which we do not usually have in mind, for the reason that as a general thing the iron loss in the armature is calculated entirely on the basis of the average density which occurs in the core at a point midway between the pole tips.

Mr. Henry Pickler:—I think we would all be very much pleased if Professor Goldsborough would explain to us by which method he found that on the top of the armature core the density was 14,000 and on the bottom 2,000.

Professor Goldsborough:—That was determined in this way—take a case, for instance, in which we have two poles, as in Fig. F, with the armature core beneath. We took the core and simply bored holes all the way through it, in regular order, as indicated, parallel to the armature shaft. Then by means of exploring coils wound through the holes, and a galvanometer, we obtained readings proportional to the flux-density in different parts of the core by breaking the field circuit. These results have all been brought out in a paper which I had the pleasure of reading before the Institute at the Boston Meeting, two or three years ago.

President Scott:—In the diagram which you first used in the two-pole machine, you showed the difference between the outside and the inside as 14,000 to 2,000. That would not apply in a two-pole, but rather in a many pole machine. A difference so great as that would hardly come in the first figure which you showed here.

PROFESSOR GOLDSBOROUGH:—That depends upon the design of the two-pole machine and especially upon the per cent. of the armature surface that is covered by the poles; these effects are much more pronounced where 80 per cent. of the armature is covered than where only 50 per cent. is covered.

PROFESSOR FRANKLIN:—I would like to call attention to a point in connection with the last statement made by Professor Goldsborough. The *distribution* (sectional) of flux in the iron parts of a dynamo cannot be determined with any accuracy at all by calculations based on the assumption that the pole faces are equi-potential surfaces (maghetically).

Non-uniform sectional distributions of flux are determined by magnetomotive forces which are of the same order of magnitude as the actual variations from constant potential (magnetic) over the pole faces. To ignore these differences is therefore to ignore, it may be, the whole of the cause which leads to non-uniform distribution.

To assume that the surface of a mass of iron under the influence of magnetizing forces is a surface of equi-potential (magnetic) is the same thing as assuming that the reluctivity of the iron is zero, and under this assumption flux distribution in the iron is absolutely indeterminate.

PROFESSOR ESTERLINE:—A number of tests made using the ballistic galvanometer and exploring coil show a very uniform distribution of the air-gap flux, with a small per cent. of fringing at the pole corners.

PROFESSOR GOLDSBOROUGH:—In connection with that I would say that in the discussion which we are having this morning, I did not start out to enter into an ultimate analysis of this problem; but to substantiate my first statement I would like to say that we have found it possible to determine with an accuracy which is greater than experimental accuracy; that is, we can calculate more closely than we can get it experimentally what the actual density is at each point of the surface of the armature, making full allowance for fringing and the variations in permeability of the iron. Now, further than this, to carry the matter to an ultimate analysis, we have taken into consideration the variations that occur in the reluctance of the iron in the body of the armature core due to variations in flux density; and in addition we have superimposed the armature reaction on top of all the other reactions, and by a method of vectors, we have found exactly the number of lines of force threading the air-gap and the armature core at all loads. The analysis shows that the core loss increases as the load comes on, owing to the fact that the points of maximum density are changed by the armature reaction.

MR. LEONARD WILSON:—I think that all designing engineers will feel very grateful to the authors of this paper for the large amount of experimental work which they have classified in this manner, and will give it the careful study it deserves. What the

designing engineer really wants is some method of rapidly and accurately calculating the core loss in armatures, and to do that he wants some method of calculating the loss in each part of the core; that is, the loss due to hysteresis and eddies in the core itself, and in the teeth, and the loss that is due to eddies in the pole pieces and in the conductors, etc.; and, having obtained methods for calculating these details, then, by actual tests, he wants to obtain some correcting factor which will make the result approximately correct for the generator as a whole. These curves, as they stand, do not enable one, without analysis, to see exactly what the results are. For instance, the curves of watts per pound and density are usually very interesting, but to assimilate them it is necessary (and it would be interesting) to know what is the approximate equation for those curves. I think for that purpose it would be very useful to plot the results on log. paper, by which means one could see at a glance approximately what the order of a curve was, that is to say, the nearest index for each part of the curve. In testing a number of direct current generators, for core loss it was found that the curve connecting core loss and total magnetic flux was of a very high order in the region of the normal working flux. That is to say, in a number of machines the core loss—which includes all open circuit electrical losses due to the rotation of the armature—will vary as perhaps the 5th or even the 8th power of the density—perhaps an average figure is the 4th power of the density, in the region of normal density. At low densities the index is quite different. I do not know that this paper gives any particulars of the loss in the teeth at high densities. I have not had time to look it through. But it seems to me that one reason for the very rapid variation of tooth loss with the density is that as the teeth get saturated there is a large amount of leakage into the slot, and consequently increased eddies in the conductor, and at normal tooth density the eddy current loss in the conductors, such as it is, increases with the magnetizing force in the teeth; that is to say, increases with the H^2 instead of B^2, and when you are working just at the bend of the saturation curve, the H^2 varies very rapidly, varies perhaps as the 10th or higher power of the density, just for that part of the curve; and that probably accounts for the high order of the curves of density and watts per pound.

MR. MAILLOUX:—I think, Mr. President, I can partly answer the question put by the last speaker in reference to an equation to express these curves. One can see at a glance that these curves can be approximately expressed by an $X\,M$ function. That is, the equation probably would be $y = b\,x^n$. There is no constant, because the curves all start from zero; consequently, the equation takes the simplest form. Doubtless it will be found that n is less than unity because the curve has a close analogy to the magnetization curve. The magnetization curve when it is plotted, has an empirical equation of the form $y = a + b\,x^n$, with

an exponent which varies between .1 and .2. It is probable that in this case the exponent would vary with the different curves somewhere between 0.5 and a few tenths. It is a very easy matter to determine the constants, and if I had thought of it I would have worked them out. In a very few minutes one can take two or three points of these curves and work out the constants, that is to say, the coefficient b, which affects the scale of ordinates, and the exponent n which affects the curvature.

DOCTOR KENNELLY:—Owing to the way in which these curves are plotted, bending down instead of up, which I think may be a matter of custom.——

MR. MAILLOUX:—I was going to refer to that. If you turn the paper horizontally, then in that case you would still have an equation of exactly the same mathematical type, which is a parabola, but the exponent now has a value greater than unity.

MR. HENRY PICKLER:—In connection with what Mr. Wilson said, I would like to ask Professor Esterline whether he tried to separate the hysteresis and the eddy loss in the armature, and what is the law that he found.

PROFESSOR ESTERLINE:—In reply I would say, that no effort was made to separate the hysteretic and the eddy current losses. The work of getting experimental results ran up very close to the time at which the paper had to be presented, and there was no time to go into those details. It is my hope to carry out the work further at some future time.

PRESIDENT SCOTT:—This paper (referring to Esterline paper), is in one sense similar to those which were presented yesterday. As Mr. Wilson brought out, this is not a simple question, but a very complex one. I noted yesterday when we were discussing the problem of lightning protection that some of our Western friends seemed a little skeptical when it was endeavored to express the subject in formulas on the blackboard; and in the present case, if some workman files his armature or bolts it together a little carelessly, these curves may be changed from the x^nth order to some order entirely different. A workman in the shop can shift these curves faster than the investigator can measure them.

MR. MAILLOUX:—I shall be very glad if the author of the paper will communicate to me the data relating to the curves, or let me have the curves in larger form to calculate the constants and give, later, in a written communication, for the TRANSACTIONS, the equation which will approximately represent every one of those curves.

PROFESSOR ESTERLINE:—I shall be very glad to do so, considering that there are 225 such curves.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2d, 1903.

CENTRAL STATION ECONOMIES.

BY W. E. GOLDSBOROUGH AND P. E. FANSLER.

As an example of the most approved modern practice, we have in the State of Indiana one of the finest and most interesting railway plants that has ever been installed. The lines of the Union Traction Company of Indiana traverse six counties of the State—Delaware, Grant, Hancock, Henry, Madison and Marion—and serve a population of 350,000 people. With its 163 miles of track, it forms the largest system in the world operated by one central power house.

It is fair to say that a comprehensive test of this system furnishes much data of interest and value, in view of the prominence which interurban systems have assumed in the industrial movements of to-day. The present paper deals with an important phase of an economic investigation undertaken during the Spring of 1902 which included every element that enters into the system. As a matter of convenience, when the problem of making a commercial efficiency test of the entire system was undertaken, the work was divided into 5 distinct divisions. These were in turn apportioned among 10 seniors of the School of Electrical Engineering of Purdue University, Lafayette, Indiana, who arranged and supervised the work under the immediate direction of the authors.

The present paper deals with a test made to determine the economies of the main power station. Messrs. Stein, Wilson, Reed and Gregg are responsible for the accuracy of the records made, upon which the conclusions herein contained are based.

The main power station is located in North Anderson, adjacent to the interurban line. It occupies a handsome building of natural-gas burned brick with a foundation of Greensburg stone, 117 feet × 165 feet; the boiler room 70 feet × 160 feet, 9 inches, and the engine and generator room 70 feet × 160 feet 9 inches inside, with a height of 35 feet in the boiler room and of 30 feet in the engine room from the floor to the roof trusses. A 10 foot basement gives room for the coal and ash-conveyor under the boiler room and for the static transformers and storage battery under the engine room.

THE BOILER ROOM.

The boiler room is provided with eight Babcock & Wilcox water tube boilers, rated at 400 h.p. each, the principal dimensions of which are:

Number of tubes, 102.

Arrangement, 16 wide and 12 high.

Size of tubes, 4″ diameter.

Two drums, 3′ diam., 16′ long.

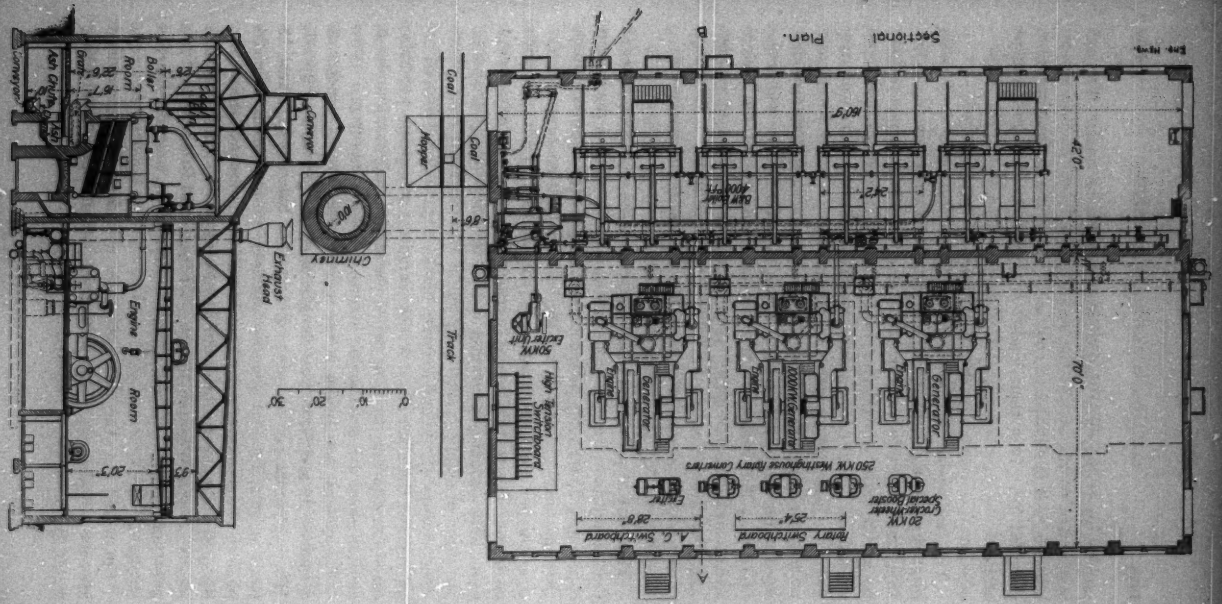
O.H. steel, tensile strength, 56,000 lbs.

Steam pressure (rated), 160 lbs.

A large brick chimney, 200 feet high, inside diam. of 10 feet, is located just south of the boiler room, and is connected to the furnaces by means of a tunnel.

The furnaces are served with fuel by Babcock & Wilcox chain grate stokers under each boiler, ample provision being made for handling the coal as follows.

Loaded cars of coal are brought to the side of the station, where a large steel hopper is constructed under the track. The coal is dumped from the cars and passes through the hopper into the coal-crusher located in the basement under the boiler room. After the coal is crushed into pieces about the size of a walnut, it falls into conveyor buckets and is carried to the top of the building and dumped automatically into large steel bins, there being one for each boiler. From these bins hang long spouts for carrying the coal from them to the hoppers of the stokers, the flow of coal being regulated by a sort of damper at the top of each spout. The grates are moved by a separate engine, as is also the conveyor. As the grates move under the boilers, coal is fed from the stoker hoppers where the amount is regulated by means of a striker. The coal is burned on this grate until it reaches the back part of the furnace, when the refuse, such as ash, etc., falls into a pit from which it is drawn


Cross Section A - B.
Boiler Room
Engine Room
Chimney
Exhaust Head
Track
Coal
Hopper
Conveyor
Ash Chute
Grate
Section on A - B.
Plan.
Exc. Mains.
Battery Switchboard
A. C. Switchboard
Exciter
Generator
250 KW Watthour Meters
250 KW Watthour Meters
20 KW Exciter
Exciter
Generator
Generator
Generator
Generator
Exciter
Exciter
Exciter

into the same conveyor buckets which carry the coal. The ash is elevated to the top of the building and deposited in a special bin, where it is allowed to cool until such time as its disposal is provided for. It is then loaded into gondola cars and hauled away.

Feed Water.

The feed water for the boilers is drawn from two deep wells located under the boiler room by means of two deep well pumps. It is raised into a large tank near the station, from which it flows by gravity into a large open heater, where it receives heat from the exhaust of all the auxiliary engines, including the air pumps. From the heater the water is forced through a 6″ feed water main by a powerful pump of which there is a duplicate for emergencies. Feed water can be delivered to any or all boilers at the will of the fireman. The water main is located on top of the boilers and so arranged that either pump may be used at any time.

A Dean double acting fire pump is located in the boiler room basement, and is used in cleaning the boilers and in case of fire.

Engine Room.

There are at present in the engine room three cross-compound Corliss automatic cut-off condensing engines, with a maximum capacity of 2,000 horse-power each, and space for a fourth unit of the same size. These engines are built under a guarantee of less than one per cent. speed variation from no load to full load, with an instantaneous variation not greater than two per cent. in any case. The economy guarantee is that the maximum steam consumption of engine, jackets, air-pump and reheating coils, when under normal steam and vacuum conditions, shall not exceed on an average the equivalent of 14½ pounds of dry steam per indicated horse-power per hour, when the engine and pump under a constant load are together indicating 1,500 horse-power.

The general dimensions of the main engines are: Diameter of cylinders, 26 and 50 inches; length of stroke, 48 inches; speed, 100 revolutions per minute; diameter of balance fly wheel 18 feet; weight, 120,000 pounds; diameter of shaft at middle, 24 inches; dimensions of main bearings, 22 by 58 inches; crank-pin, 8½ by 8½ inches; cross-head pin 7 by 8½ inches; length of connecting rod, center to center, 12 feet. An improved Rites inertia type governor gives a cut-off variable from zero to three-fourths stroke.

Connected to the low pressure cylinders of the engines are jet condensers, the condensed steam and condensing water from which is allowed to escape into a private sewer.

However, special connections are made at all joints and at the separators in order that the water in the steam pipes may be drained into the Holly system and returned to the boilers to be evaporated.

The engines may be run non-condensing if it is so desired, and for this purpose large exhaust pipes are provided to carry off the exhaust steam.

Direct connected to each of the three engines is a 1,000 k.w. three-phase generator with rotating fields, separately excited, and designed for 100 revolutions per minute. With 32 poles this gives 1,600 cycles per minute. Each generator has a normal capacity of 1,600 amperes in each of the three phases, the full load voltage being 400. Three means are provided for the field excitation: (1) A 50 k.w. direct current generator, direct connected to a three-phase induction motor; (2) a 50 k.w. direct current generator, giving 125 volts, direct connected to a high speed Ball engine; (3) the storage battery is tapped for 125 volts, to be used in an emergency.

This plant also contains a substation consisting of a storage battery, a booster, three rotaries and a switchboard. This substation equipment is the same as that of the remaining substations, except that it is of larger capacity.

In the generator room are two switchboards of white marble, mounted on an angle-iron frame. One of these boards contains the instruments and regulating apparatus for the alternating current output of the entire plant and the other is a typical substation switchboard. The leads from each of the generators are led direct to a generator panel. Each leg of the three-phase circuit from each generator is connected through a single pole single-throw 2,000 ampere switch to one of the low potential bus-bars which run the entire length of the board, and two of the legs of the circuit from each generator are provided with 2,000 ampere non-automatic circuit breakers. There are three alternating current ammeters on each generator panel reading up to 2,500 amperes, one in each phase, and two 750 k.w. indicating wattmeters are connected between the phases of each machine. The field circuit of each generator is led to its corresponding panel and has in its circuit a field rheostat and a 200 ampere direct current ammeter. The standard Westinghouse synchronizing apparatus, ground detector and pilot lamps are also placed on each generator panel.

The load panel, placed next to the generator panels, contains

the instruments for reading the total current on the bus-bars. There are three alternating current ammeters, one in each leg of the circuit reading up to 10,000 amperes, two direct reading Niagara type wattmeters, and one 5,000 k.w. integrating polyphase recording wattmeter reading the station output.

A three-phase circuit is tapped from the low potential bus-bars to each of the low-potential alternating current feeder panels, each leg of the circuit running to a single pole switch, and two of the legs having automatic circuit breakers in them. The lines then run through ammeters to the 250 k.w. step-up transformers in the basement where the current is stepped up to 16,000 volts. The high potential lines pass through circuit breakers on leaving the transformers, and then go out over the four sets of high-potential feeder lines. A lightning arrester is connected in each high-potential line as it leaves the building.

The two remaining panels on this board are for the exciters, one for the motor-driven and the other for the steam driven. The engine-driven exciter panel contains a 150 volt scale voltmeter and an ammeter reading up to 500 amperes for the field circuit. The exciter circuit passes through a circuit breaker to the pair of 125 volt field bus-bars which run behind the generator panels. From these bus-bars the circuits are led to each generator field through a pair of plug switches, an ammeter and a field rheostat. This exciter panel also contains a rheostat for the shunt field of the exciter and a double throw two-pole switch, the function of which is to connect either the exciter or the 125 volt storage battery section to the field bus-bars as desired. The motor driven exciter panel contains a switch for the induction motor, a rheostat for the exciter field, an ammeter and two two-pole knife switches.

None of the alternating current ammeters or wattmeters have their current coils directly in the circuit, but take current from the secondaries of series bus transformers in which the bus-bar forms the one-turn primary—the ratio of conversion of current being 8,000/5 in the instruments on the load panel and 20,000/5 on the generator panel. In calibrating the ammeters, a standard Stanley hot-wire ammeter, with shunts, was put in series with the secondaries of the transformers and the instrument on the board. In calibrating the wattmeters, the current coil of a standard Weston wattmeter was connected in series with the current coil of the switchboard instrument, and the pressure coil connected in parallel. As the pressure coil of the

Weston is built for 150 volts. German silver resistance had to be connected in series with it and its value as a multiplier found by calibration with a Kelvin balance. The station voltmeters were connected in parallel with a standard Weston alternating and direct current voltmeter for calibration. All standards used in calibration were calibrated by means of a Kelvin balance and all the test readings corrected accordingly. As the instruments had to be calibrated, and connections made while the plant was in operation, and as it was difficult to get readings over a very wide range without spending time in waiting for the load to vary, it took almost two weeks to complete the calibrations.

Method of Procedure.

boiler test.

Water.—In order to ascertain the amount of water used in the boilers, it was decided that the ordinary method of weighing the water by barrels was altogether impracticable, so a Venturi meter was installed in the feed water main above the boilers. This meter is nothing more nor less than a graduated nozzle, so arranged that pressure gages may be inserted at the throat and at the up-stream end. By the difference in the pressure readings of these gauges, noted every 15 minutes, and the known area of the nozzle, the cubic feet of water flowing in a given time may be calculated. The temperature of the water was also taken.

Prior to the test the Venturi meter was calibrated in the Engineering laboratory of Purdue University. The meter was connected to a pump and means provided whereby the up-stream pressure was kept constant at about the boiler pressure maintained in the boiler room at Anderson, while the throat pressure was varied. In this work of calibration a weir was made use of and hook gauge readings were taken, so that the actual rate of flow of water could be calculated for the various differences in pressure of the meter gauges.

For the determination of the amount of water used by the boilers during the test a curve of flow over the weir (Fig. 1), was plotted against the differences in the indications of the gauges on the Venturi meter and from this curve the actual rate of flow of water to the boilers was found from the records made every fifteen minutes during the test. A curve was then constructed, the ordinates of which represent the rate of flow of water plotted

against time. By integrating this curve for any desired interval of time the number of cubic feet of water used during the said interval can be determined and the weight of the water used found by multiplying by 60.3 the density of water at 185° F., the feed water temperature.

Coal.—The method employed in weighing the coal was to close all the coal chutes but one and to take all the coal used in the test from one bin. Coal was allowed to fall to the floor instead of into the stoker hoppers, and was then thrown into wheelbarrows and weighed; the contents of the barrows was then dumped on the floor in front of the several boilers and thrown into the stoker hoppers by hand. In this way the accurate weight of coal used was kept on the coal log together with the time of weighing, so that a curve of coal against time could be plotted.

A sample of coal was taken every 12 hours by the A. S. M. E. method, and tested for moisture and calorific value.

Special.—A thermometer inserted in the feed-water pipe registered the temperature of the water entering the heater, while a thermometer inserted in the Venturi meter registered the temperature of the water entering the boiler.

The barometric pressure was recorded by an aneroid barometer placed in the engine room.

The boiler pressure was read from the gauge over the central pair of six boilers which were in service during the three days' test, though all of the boiler gauges were carefully calibrated prior to the test.

The engine room temperature was indicated by a thermometer hung from one of the voltmeter brackets in front of the switchboard but not in proximity to any of the switches or cables.

The initial steam pressure, receiver pressure and vacuum in inches were read from the gauges on the engine board, while the engine speed was determined with revolution counters in the usual manner.

The time of starting and stopping all auxiliary engines was carefully noted during the test on the supposition that this record would be of value when considered in connection with a separate test to be made of the auxiliaries to determine the amount of steam used by them.

Subsequently, owing to defects in the valves of the boiler room pipe line, it was found impossible to separate a pair of the boilers from the remainder of the battery effectively, and consequently the special test of the auxiliaries had to be given up.

As stated below, in figuring out the net engine economy an allowance of 15 per cent. has been made for the amount of steam consumed by the auxiliaries.

The water level in the boilers was kept as nearly as possible at the same level throughout the test and was noted to be the same at the end as at the beginning of the test.

Engine Test.—The engines were indicated at both ends of both cylinders, pantagraph reducing motions being exclusively employed.

Indicator diagrams were taken at intervals of fifteen minutes throughout the test, care being taken to get plain diagrams simultaneously on all cylinders. The r.p.m. was also carefully noted on the engine log together with steam gauge readings, vacuum gauge readings, receiver gauge readings and barometer readings.

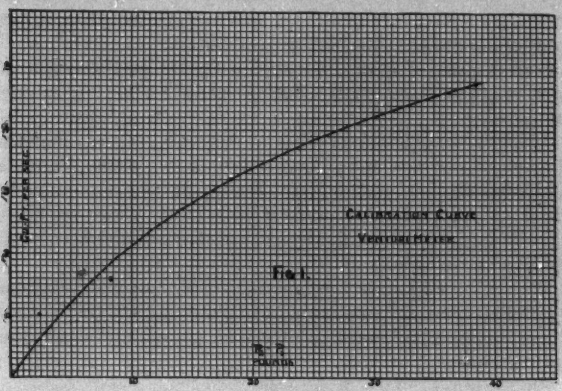
The drain pipes from the separators were disconnected from the Holly system and so arranged that the drip could be weighed, thus affording a means of calculating the percentage of moisture in the steam.

An account was kept of the time the exciter engine was run, but the time was so short that it did not figure in the results.

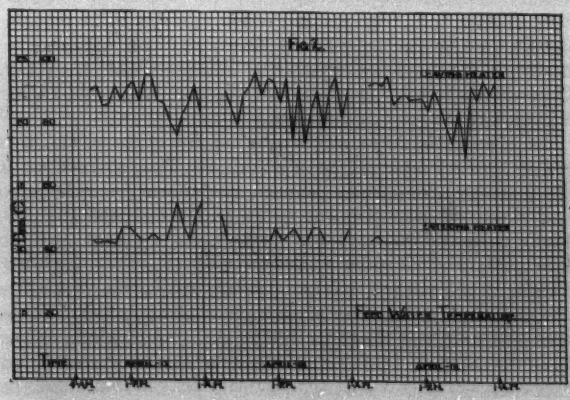
Generator Test.—On the switchboard, readings of the instruments on each generator panel were noted, *i. e.*, of an ammeter, both indicating wattmeters and of the ammeter in the exciting circuit. On the load panel, in addition to these readings, the reading of the polyphase integrating wattmeter was also taken. Other readings recorded were—the bus-bar voltage, the exciter voltage and the total field current.

Each generator output is given by the sum of the two indicating wattmeters on each generator board. The total output of the generators, in a similar manner, is obtained from the readings of the two indicating wattmeters on the load panel, and the sum of these two load panel wattmeter readings should equal the sum of the four indicating wattmeter readings on the generator panels. The great inertia of the moving parts of the wattmeters and the insufficient number of observers, making it impossible to take all readings at the same instant, will probably account for any discrepancies in this part of the data, as a very small swing over the scales will make an appreciable error. In most cases the sum of the four wattmeter readings check very closely with the load panel readings. In several instances use was made of this fact in detecting errors in the load panel readings. For instance,

in plotting the engine and generator output, the two curves were found to follow each other very nicely. In several instances, however, the engine would indicate a large instantaneous



load while the load panel readings for the same time would not indicate a corresponding increase in the generator output



recourse to the generator logs would invariably either check the load panel readings and thus show the error in the engine output due to the fact that the cards were not taken at the same instant

or would check with the engine output showing the load panel readings to be in error.

Results of the Engine and Boiler Tests.—In the records which follow it is not attempted to give anything more than a summary of the records which were made on the three days during which the tests were in progress. The results here presented are deemed to be sufficiently accurate inasmuch as the tabulated data have been worked over twice and in some instances three times in order that the possibility of appreciable error entering at any point might be avoided.

In Table I. is given a resumé of the data covering the barometric pressure, the boiler pressure and the feed water temperature. From this table it will be seen that the variations in the barometric pressure were unimportant. The variations in the steam pressure were, however, at times quite marked. In Fig. 3

TABLE I.

GENERAL AVERAGES.
PRESSURES AND TEMPERATURES.

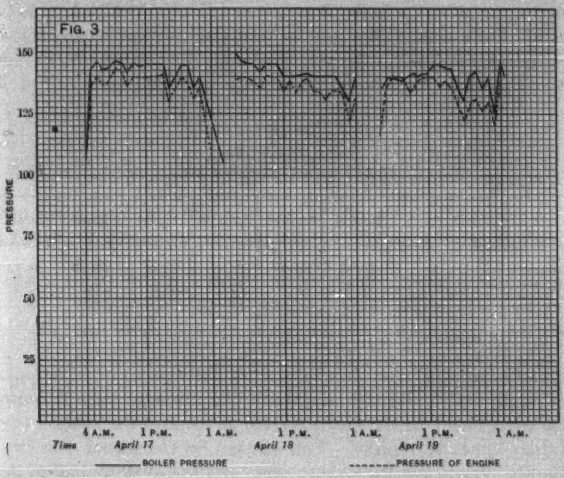
	April 17.	April 18.	April 19.	Total.	Highest.	Lowest.
Barometer in inches Hg.....	28.63	28.62	28.61	28.62	28.70	28.55
Feed water entering heater°C.	12.00	11.34	11.02	11.45	14 0	10.8
Feed water entering boiler°C.	88.7	88.5	88.6	88.6	97.0	70.8
Boiler pressure lbs. per sq. in.	137.7	141.5	139.4	139.5	150.0	125.0

a graphic record shows the character of these pressure variations. On each day during the afternoon the pressure fell off quite markedly owing to the fact that late in the day the load on the station comes on rapidly. The demand on the station was frequently very heavy for a short time, and as the firing had to be adjusted to the average load, fluctuations necessarily took place in the boiler pressure. The average boiler pressure is very close to 140 pounds; the maximum record being 150 pounds and the minimum 125 pounds during service hours.

The temperature of the water entering the heaters was practically constant at 11° centigrade throughout the tests. The temperature of the feed water leaving the heaters was subject to variations similar in character to those in the boiler pressure, but, more marked in degree. These variations in the temperature of the feed water leaving the heaters and entering the boilers is, however, largely due to a different cause. Since the feed water is heated by the

exhaust from the auxiliaries its temperature is dependent upon the number of these auxiliaries in service. Late in the day some of the auxiliaries, especially the coal crushing and the conveying apparatus, are thrown out of service. During the test the temperature of the feed water entering the boilers varied from 96° centigrade to 70° centigrade.

The general results of the boiler tests are given in Tables II. and III. and recorded graphically in Figs. 4, 5 and 6. During all three days of the tests the supply of water to the boilers was fairly uniform, at 50,000 pounds per hour. This rate was exceeded slightly on all three days, and on April 19th the average



ran up to 57,000 pounds per hour. The rate at which the coal was fired, however, was subject to rather marked fluctuations. On the first morning of the tests, owing to the facts that the coal handlers were " green " and the usual procedure in the station changed on account of the coal chutes being thrown out of commission and the coal shoveled from the boiler room floor by hand, coal was fired at a very high rate. Subsequent to the first morning, however, no irregularities of any importance occurred, as, during the remainder of the test, the amount of coal on the boiler room floor for delivery to the grates was supervised by the head fireman, and kept fairly proportional to the load on the station. This is especially true of April 18th and 19th.

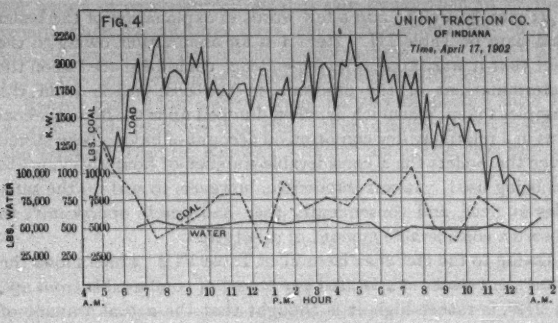


FIG. 4
UNION TRACTION CO.
OF INDIANA
Time, April 17, 1902
K.W.
LBS. COAL
LBS. WATER
LOAD
COAL
WATER
HOUR
A.M.
P.M.
A.M.

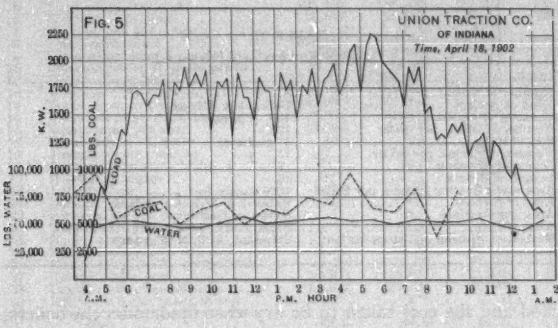


FIG. 5
UNION TRACTION CO.
OF INDIANA
Time, April 18, 1902
K.W.
LBS. COAL
LBS. WATER
LOAD
COAL
WATER
HOUR
P.M.
A.M.

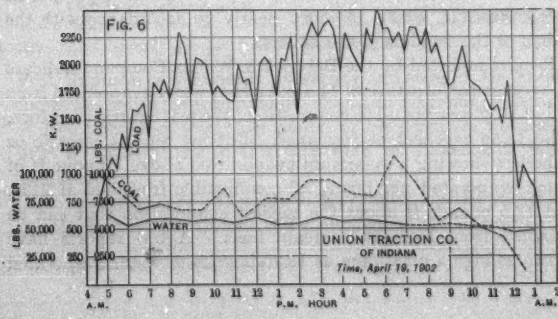


FIG. 6
K.W.
LBS. COAL
LBS. WATER
LOAD
COAL
WATER
UNION TRACTION CO.
OF INDIANA
Time, April 19, 1902
HOUR
A.M.
P.M.
A.M.

It may be well to add a few words in explanation of the boiler test data of Table III. Item 4 is an assumption, owing to the fact that it was thought no dependence could be placed upon the determinations of the moisture in the coal made from the samples taken, inasmuch as, when dumped upon the floor, the coal was in a relatively dry condition on account of having been stored over the boilers for a considerable number of hours previous to its being used. It was impossible, however, to seal up the samples at once, and consequently they had ample opportunity to absorb a considerable amount of moisture.

Owing to the fact that Item 27 of Table VIII., which shows the equivalent water evaporated per pound of combustible from and at 212°, is rather high, it is thought that the actual amount of moisture in the coal was less rather than greater than the assumed value of 6 per cent. If the extreme condition is as-

TABLE II.

DATA ON BOILERS AND FURNACE.

Number of boilers	8
Kind of Boilers	Babcock & Wilcox.
Capacity of boilers	400 h.p. each.
Number of tubes, per boiler	102.
Size of tubes	4″ diameter.
Number of drums, per boiler	2.
Diameter of drums	3′.
Length of drums	16′.
Area water heating surface, per boiler	4000 square feet.
Kind of furnace	Babcock & Wilcox standard.
Area grate surface	66 square feet.
Kind of fuel	Brazil block, mine run.
Method of starting and stopping test	Standard, A. S. M. E. code.

sumed and the coal taken to be dry when fired under the boilers, Item 27 will be reduced from 12.30 pounds evaporated per pound of combustible to 11.65 pounds evaporated per pound of combustible, which is more nearly in accordance with the claims of the builders of the boilers.

Results reported by the Babcock & Wilcox Company indicate an average performance of 11.4 pounds of water evaporated from and at 212°, per pound of combustible; the test figures, therefore, indicate an excellent performance. But few reports come to us of boilers showing a maximum evaporation above 12 pounds of water evaporated per pound of combustible from and at 212°, and 12.5 pounds is about the highest evaporation that can be obtained from high-grade steam fuels. A few reports have shown as high a maximum as 13.25 pounds of water evaporated

per pound of combustible, but it is safe to say that an average record made during three days test at Anderson, Ind., of 12.3 pounds evaporated per pound of combustible from and at 212° is an excellent showing under conditions of variable load.

Recent tests upon electric street railway properties show an economy somewhat less than this. For instance, a test made of the Oshkosh Electric Railway System* about one year ago by

TABLE III.

RESULTS OF BOILER TESTS.

No.	Quantity.	April 17.	April 18.	April 19.	Total.
1	Date of trial	April 17.	April 18.	April 19.	Total.
2	Duration of trial	24 Hrs.	24 Hrs.	24 Hrs.	72 Hrs.
3	Weight coal as fired	144,500	145,000	146,000	435,500
4	Moisture in coal	6%	6%	6%	6%
5	Total weight dry coal	135,800	136,300	137,200	409,300
6	Total ash and refuse	16,460	16,540	16,640	49 640
7	Per cent. ash and refuse	11.4	11.4	11.4	11.4
8	Total combustible	119,340	119,760	120,560	359,660
9	Dry coal per hour	5.650	5,700	5,730	5,690
10	Dry coal per sq. ft. grate per hr.	14.25	14.40	14.48	14.39
11	Total water to boiler	1,242,000	1,256,600	1,256,600	3,755,200
12	Water actually evap.	1,229,700	1,244,000	1,244,000	3,717,700
13	Equiv. from and at 212	1,487,000	1,505,000	1,505,000	4,497,700
14	Water per hour, corrected	51,200	52,000	52,000	51,700
15	Equiv. evap. per hour	62,000	62,800	62,200	62,400
16	Equiv. per sq. ft. grate	157	158	158	157.8
17	Average steam pressure	137.7	141.5	139.4	139.5
18	Temp. feed entering boiler	88.7	88.5	88.6	88.6
19	Moisture in steam	.99%	.99%	.99%	.99%
20	H.P. developed	1,800	1,820	1,820	1,800
21	Builders' rated h.p.	2,400	2,400	2,400	2,400
22	Per cent. b.r.h.p. developed	75	75.8	75.8	75.3
23	Water evap. per lb. coal	8.51	8.58	8.52	8.53
24	Equiv. evap. per lb. coal	10.21	10.30	10.22	10.24
25	Equiv. evap. per lb. dry coal	10.86	10.96	10.89	10.90
26	Equiv. evap. per lb. combustible	12.27	12.36	12.29	12.30
27	Calorific value coal	12,500	12,500	12,500	12,500
28	Calorific value combustible	14,100	14,100	14,100	14,100
29	Efficiency boiler based on coal	79.1	79.7	81.1	79.6
30	Efficiency boiler based on combustible	83.9	84.6	84.3	84.3
31	Economy feed water heater	6.15	6.20	6.23	6.19
32	Cost per ton of 2,000 lbs.	$1.35	$1.35	$1.35	$1.35
33	Cost of coal required to evaporate 1,000 lbs of water from and at 212°	$.0655	$.0651	$.0657	$.0654

Prof. Swenson of Wisconsin University and some of his students shows the boiler plant to have developed an economic evaporation of 10.6 pounds of water per pound of combustible, from and at 212° F. The boilers in this case were of Babcock & Wilcox manufacture.

An elaborate test was made in May, 1898, by the students of the Massachusetts Institute of Technology on the Harvard Power

*_Street Railway Review_, September 15, 1898.

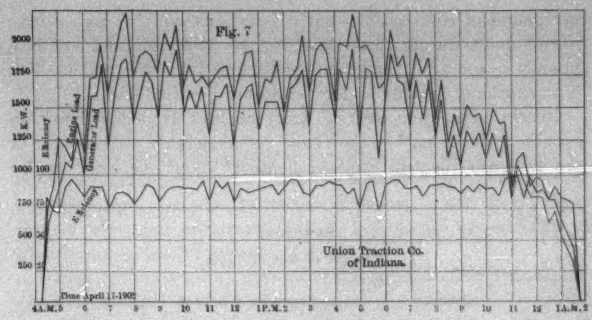


Fig. 7
2000
1750
1500
1250
1000
750
500
250
K.W.
100
75
50
25
E.R.Railway
Railway Load
Generator Load
E.R.Railway
Union Traction Co.
of Indiana.
Time April 17-1902
4A.M. 5 6 7 8 9 10 11 12 1P.M. 2 3 4 5 6 7 8 9 10 11 12 1A.M. 2

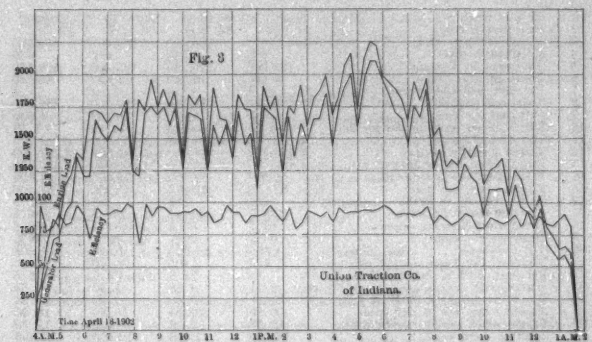


Fig. 8
2000
1750
1500
1250
1000
750
500
250
K.W.
100
75
50
25
E.R.Railway
Railway Load
Generator Load
E.R.Railway
Union Traction Co.
of Indiana.
Time April 18-1902
4A.M. 5 6 7 8 9 10 11 12 1P.M. 2 3 4 5 6 7 8 9 10 11 12 1A.M. 2

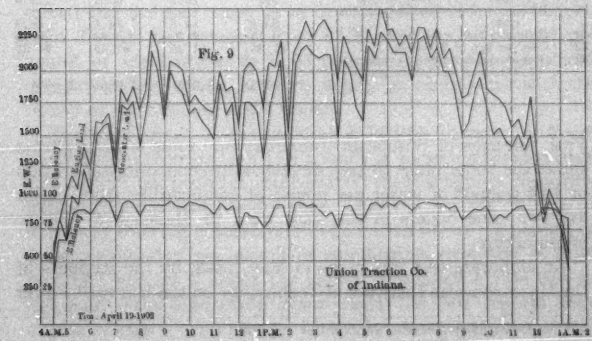


Fig. 9
2250
2000
1750
1500
1250
1000
750
500
250
K.W.
100
75
50
25
E.R.Railway
Railway Load
Generator Load
E.R.Railway
Union Traction Co.
of Indiana.
Time April 19-1902
4A.M. 5 6 7 8 9 10 11 12 1P.M. 2 3 4 5 6 7 8 9 10 11 12 1A.M. 2

Station of the Boston Elevated Railway Company. This station is equipped with six Babcock & Wilcox water-tube boilers, developing a total capacity of 3,000 h.p. The report shows that 11.3 pounds of water were evaporated from and at 212° per pound of combustible, there being 1 per cent. of moisture in the coal and 5.9 per cent. of ashes and clinkers. Other points of comparison are that in the Harvard test the average boiler pressure was 168 pounds against 140 pounds at Anderson. The average temperature of feed water entering the boilers was 209° F. at Harvard against 191° F. at Anderson, and the heat gained in heaters and economizers as compared to the total heat acquired was 7.6 per cent. at Harvard against 6.2 per cent. at Anderson. The Harvard test offers the best comparison with the Anderson tests of any that has come to the attention of the authors, and the Anderson tests show the boilers to have developed a higher economy.

Inasmuch as the conditions governing the loading of these stations were presumably similar in character, the Harvard and Anderson tests may be considered fairly representative of American practice on electric roads operating under conditions approximating those which obtain in the suburban traffic service of steam railroads.

The efficiency of the boilers expressed in terms of the total calorific power of the coal is 79.6 per cent. This is a very creditable showing in view of the fact that but 75.3 per cent. of the builders' rating was developed by the boilers.

The adjustment of the boiler capacity to the requirements of the station is better than these figures indicate, inasmuch as, owing to the fluctuating character of the load, the demand upon the boilers frequently equalled—and at times exceeded—their rated capacity.

Engines.

The efficiency developed by the engines during these tests is not so good as might have been expected. During the major portion of the time two engines were in service. Engine No. 1 was operated for 24¾ hours, Engine No. 2 for 41¾ hours, and Engine No. 3 for 55 hours. Notwithstanding the rapid and excessive fluctuations in the load, the same was remarkably well divided between the engines, and comparatively little surging can be traced from the records. In Fig. 10 curves are plotted showing the distribution of the load between engines No. 2 and No. 3 on April 17th. If these curves are scrutinized in con-

nection with the load curve of Fig. 7, it will be seen that the division of the load between the two engines is almost perfect, and that the load on the station was comparatively steady when considered as representing street railway performance during the noon hours. Late in the day, when the load had fallen off and the engines were relatively lightly loaded, a slight see-sawing is noticeable, particularly between 6 and 9 P. M.

Curves 8 and 9 show the character of the load on the station during the second and third days of the test, and it will be noticed that the variations in the load were much more marked on these days than on the first day. The variations are reflected in Curves 11 and 12, which show the division of the load between Engines 2 and 3 on both days. On April 18th Engine No. 3 varied considerably in the amount of the load it carried relatively to the amount carried by Engine No. 2. This is marked between the hours of 4 and 8 P. M. During this time the load on Engine No. 2 was comparatively steady, while the variations in the load were taken up by Engine No. 3. That the behavior of the engines on April 18th is not so good as that on April 17th is attributed to there being much heavier changes in the load on the station on the 18th than on the 17th. On April 19th, as shown in Fig. 9, the changes in the load were particularly heavy. Especially is this true at noon, 2 and 4 P. M. Each of these variations is indicated in Fig. 12 by very marked fluctuations in the load of Engine No. 3, which at 8.30 o'clock, when a sudden load was thrown on the station, took the peak as well as the depression which followed at 9 o'clock. From indications contained in the distribution load curves shown in Figs. 10, 11 and 12, it is fair to assume that Engines 1 and 2 were better regulated and adjusted for their work than was Engine No. 3. It is hardly thought that the bad behavior of Engine No. 3 can be entirely attributed to the fluctuations in the load but rather to some imperfection in the governing mechanism of the engine whereby the peripheral velocity of its fly wheel was accelerated or retarded relatively to the velocity of the periphery of the fly wheel of Engine No. 2. In Fig. 14 a portion of the engine data has been plotted for the purpose of illustrating the load distribution between the high and low pressure cylinders and between the h.e. and c.e. of the cylinders. The high pressure cylinder of Engine No. 2 takes most of the load, but the division of the load between the h.e. and c.e. of the cylinders is fairly uniform. In the case of both cylinders the c.e. develops slightly higher power than does the h.e.

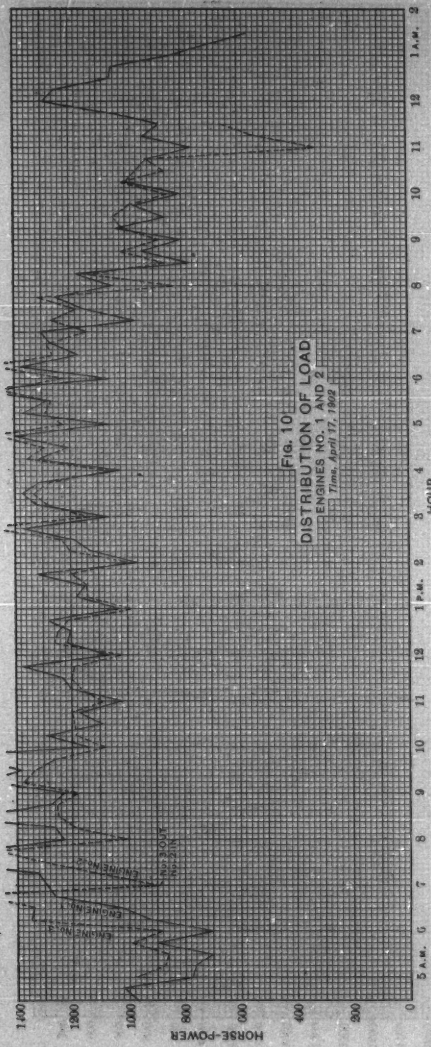


FIG. 10

DISTRIBUTION OF LOAD

ENGINES NO. 1 AND 2

Time, April 17, 1902

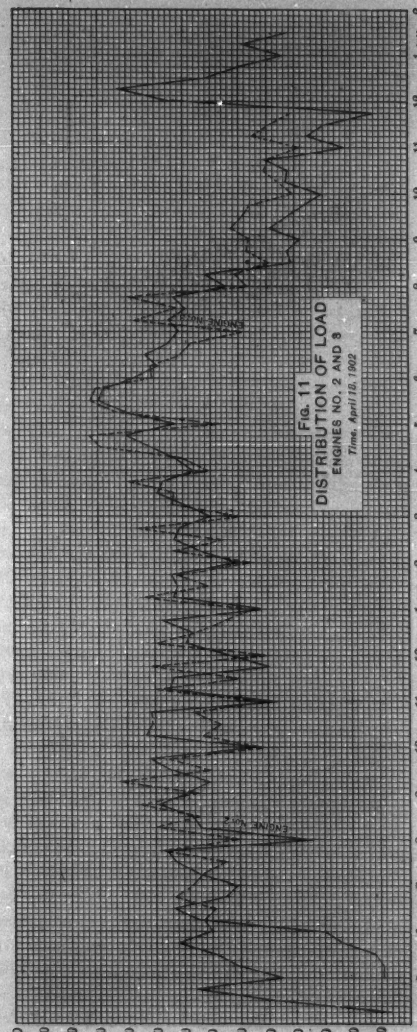


Fig. 11
DISTRIBUTION OF LOAD
ENGINES NO. 2 AND 3
Time, April 18, 1902
HORSE-POWER
HOUR
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
5 A.M. 6 7 8 9 10 11 12 1 P.M. 3 4 5 6 7 8 9 10 11 12 1 A.M. 3

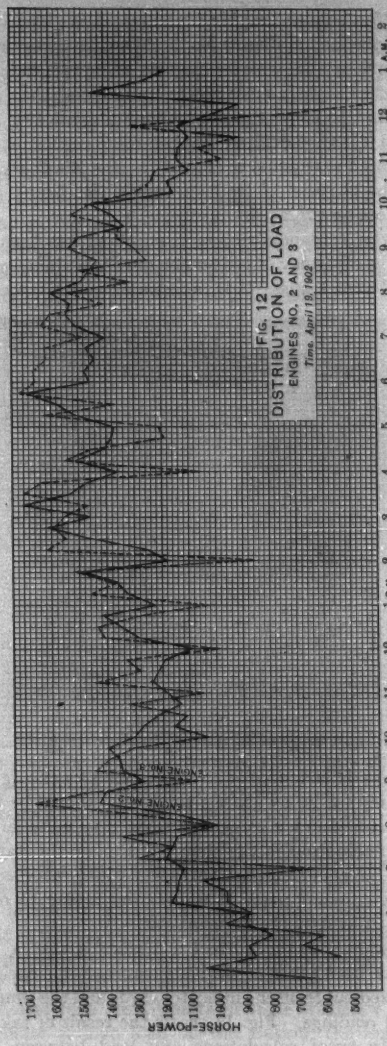
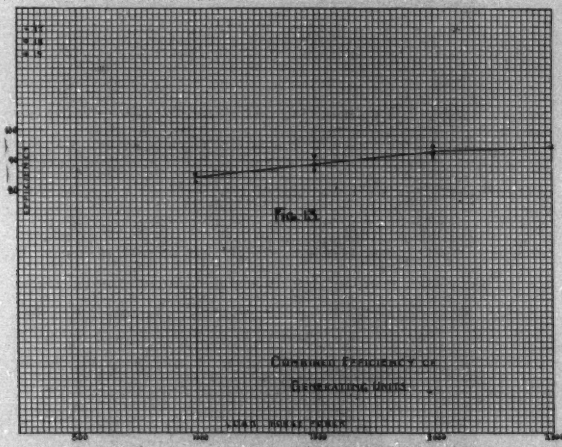


FIG. 12
DISTRIBUTION OF LOAD
ENGINES NO. 2 AND 3
Time, April 19, 1902
HORSE-POWER
HOUR
5 A.M. 6 7 8 9 10 11 12 1 P.M. 2 3 4 5 6 7 8 9 10 11 12 1 A.M. 2

In Fig. 15 a similar graphic presentation is given of the distribution of the load in Engine No. 3. The high pressure cylinder here also develops the greater amount of power, and in the c.e. of the cylinders slightly more power is developed than in the h.e.

Figs. 14 and 15 cover the same hours of April 19th, and comparing them it is very evident that the speed regulation of engine No. 3 was in no wise equal to that of engine No. 2, owing to the fact that the changes of load on engine No. 3 are greatly in excess of those on engine No. 2.

As a matter of general interest, an effort has been made to determine the efficiency of conversion of the combined generating units at different loads. It is necessarily quite impossible that



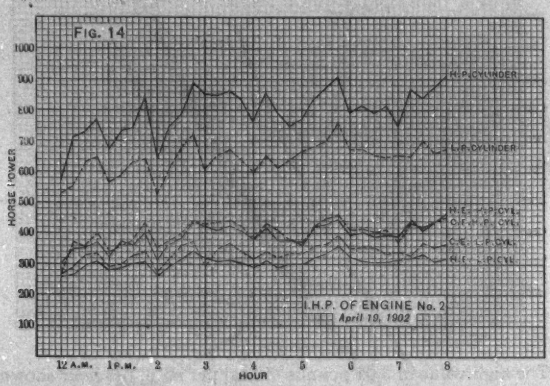
the efficiencies determined for any given load by taking the ratio of the total output in k.w. to the total i.h.p. should be the same. The energy stored in the fly-wheels takes up a considerable portion of the fluctuation in the electrical load on the station, and, furthermore, errors are always introduced into recorded data by observers in different parts of the station failing to read their instruments at exactly the same instant.

In approximating the correct efficiency curve a series of averages has been taken of the instantaneous efficiencies of conversion worked out from the indicator cards and the simultaneous switchboard readings. Fig. 13 shows the result of taking these averages. In these calculations any load between 87.5 and

112.5 per cent. was assumed to be full load; loads between 62.5 and 87.5 per cent., three-quarters load; and between 37.5 and 62.5 per cent., one half load. All points above 112.5 per cent. were assumed to be 25 per cent. overload.

The great number of readings available made it possible to secure a very close approximation of the efficiency of the generating units and the efficiency curve of Fig. 13 probably quite accurately represents their performance. The curve of Fig. 13 shows that at full load the generating units developed an efficiency of about 93 per cent. and that at one-half load they developed an efficiency of about 84 per cent. These values are excellent and indicate a high type of machinery.

The average efficiency of the generating units, *i.e.*, the ratio of

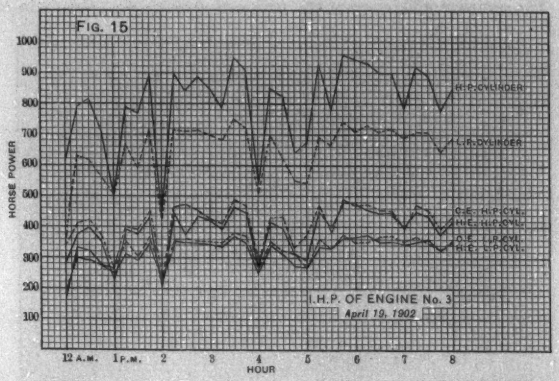


the generator curves and the i.h.p. curves of Figs. 7, 8 and 9 is nearly 90 per cent., as shown in Item 12 of Table VIII. The efficiency curves of Figs. 7, 8 and 9 give fairly constant results. In some instances the instantaneous efficiency falls as low as 70 per cent., and at times it rises above 95 per cent. No values, however, occur above 100 per cent., and this is a matter for remark when it is remembered that a large amount of energy is stored in the fly wheels and that, where the load is varying rapidly, it is not an unusual thing for the readings of the electrical instruments to show an amount of power delivered in excess of the indicated power of the engines.

In the Anderson tests points of high efficiency follow very closely points of high load on the station, the low efficiencies

coming at points of low load. This is as it should be and indicates good regulation.

In Table IV. results are recorded which show the economy of the station in terms of the coal and steam required to develop an i.h.p. hour and a k.w. hour for the different days and for the whole test. It must be remembered that the results here recorded include the steam used by the auxiliaries. The average coal consumption per i.h.p. per hour is 2.85 pounds. The best economy was developed on the 19th, when an average of but 2.65 pounds of coal was required in developing one i.h.p. This is probably due to the fact that the load was heavy and quite steady for a number of hours on the afternoon of the 19th.



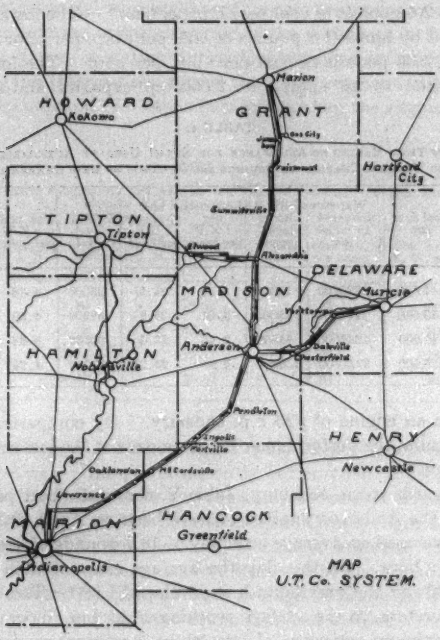
The high value of 3.01 pounds of coal per i.h.p. per hour shown on the 18th comes from the fact that on the 18th the variations in the load were heavy and there was no balancing period of heavy load during the latter part of the day. In other words, the fires had to be built up to carry the heavy load at 5 o'clock; while immediately after 5 o'clock the load fell off. On the 19th the period of heavy load extended on until 9 o'clock, beginning as early as 2 o'clock in the afternoon.

The weights of steam required to develop an i.h.p., as given in Table IV., vary from 22.6 pounds on the 19th to 23.9 pounds on the 17th. These values are high, even though they include the steam used by the auxiliaries.

In approximating the actual coal and steam economy of the engines and generators the assumption has been made that the auxiliaries require 15 per cent. of the steam generated. It is not

believed that this percentage is too high, in view of the fact that a considerable amount of power is developed by relatively small engines in operating the crushing and conveying machinery, the automatic stokers, pumps, etc.

A great deal of data as to the amount of power which auxiliaries consume is not available. Results recently published by C. D. Taite and R. S. Doune* give a comparison between steam and



MAP
U.T. Co. SYSTEM.

electrically operated auxiliaries in central stations and show that electrically operated auxiliaries require from 6.5 to 8.5 per cent. of the total power generated, whereas steam driven auxiliaries require upwards of twice this amount.

*A paper presented at a meeting of the British Institution of Electrical Engineers, April 7, 1903.

The records in Table V. show that on April 19th an i.h.p. hour was developed with an expenditure of 2.25 pounds of coal; and the average for the three days shows that an i.h.p. hour was developed by 2.42 pounds of coal. The average of seven tests of compound condensing Corliss, Greene, McIntosh and Seymour, and simple valve motion compound engines, reported by Prof. R. C. Carpenter of Cornell University in a paper read at the Cornell meeting of the New York Street Railway Association, 1899, is 2.6 pounds of coal per i.h.p. per hour*. The lowest value reported by him is 1.8 pounds of coal per i.h.p. per hour and the highest 4.06 pounds of coal per i.h.p. per hour. The low value is credited to an engine of 2,000 h.p. capacity and the high

TABLE 4.

RESULTS OF TESTS MAKING NO ALLOWANCE FOR STEAM USED BY AUXILIARIES. TOTAL COAL AND WATER IS CHARGED TO ENGINES AND DYNAMOS OF MAIN GENERATING SETS.

Date Apr.	Coal fired lbs.	Water delivered to boiler lbs.	I. H. P. hours developed.	Lbs. coal per I.H.P per hour.	Lbs steam per I.H.P. per hour.	K. W. H. developed.	Lbs. coal per K.W. per hour.	Lbs. steam per K.W. per hour.
17	144,500	1229700	51300	2.82	23.9	33000	4.38	37.2
18	145,000	1244000	48000	3.01	25.9	32200	4.50	38.6
19	146,000	1244000	55000	2.65	22.6	36700	3.98	33.9
3 days.	435,500	3717700	153820	2.85	24.25	101900	4.28	36.8

value to an engine of 825 h.p. capacity. By comparison with these results the performance of the engines at Anderson is very creditable.

As regards steam economy, Table V. shows the best performance of the Anderson engines to have been on April 19th when they developed an average economy of 19.7 pounds of steam per i.h.p. per hour. On this day the average i.h.p. of each engine was 1 230 and the maximum h.p. developed 1,690. The engines were, therefore, on the average, working under but 60 per cent. of their maximum capacity. Under these conditions an economy of 19.7 pounds of steam per i.h.p. per hour is not so bad, and, in fact, may be taken as representing creditable performance. The average of the tests reported by Prof. Carpenter was 18.8 pounds per i.h.p. per hour. The 2,000 h.p. engine before referred to developed an i.h.p. on 14.5 pounds of steam while the 825 h.p.

*The Fuel Economy of Railway Engines, *Street Railway Review*, Oct. 15, 1899.

engine required 22.7 pounds of steam. Unfortunately the conditions of loading are not specified in these cases so that the comparison fails in some particulars.

In the case of the test on the Harvard station previously mentioned of engines made by E. P. Allis Company, each of which has a nominal capacity of 1,800 h.p., the engines are shown to have developed an i.h.p. with a consumption of between 14 and 15 pounds of water. This is a high economy for street railway work. Unfortunately no curves or other data are given from which any determination of the character of the variations in the load upon the Harvard station during the tests can be made. On May 10th the Harvard test record shows the engines to have developed an i.h.p. on 14.05 pounds of steam when the engines were

TABLE 5.

RESULTS OF TESTS FIGURED ON THE ASSUMPTION THAT 15 PER CENT. OF THE STEAM GENERATED WAS USED BY THE AUXILIARIES.

Date, April.	Lbs. coal per I. H. P. per hour.	Lbs. steam per I. H. P. per hour.	Lbs. coal per K. W. per hour.	Lbs. steam per K. W. per hour.
17	2.40	19.22	3.72	31.6
18	2.56	22.0	3.82	32.8
19	2.25	19.7	3.38	28.8
3 days.	2.42	20.61	3.64	31.3

under an average load amounting to only 72 per cent. of their normal rating. This performance is better than anything reported by Prof. Carpenter and shows a performance 29 per cent. better than that of the Rice & Sargent Corliss engines in the Anderson station. In operating efficiency, however, the machinery in the Anderson station seems to be the equal of that in the Harvard station, as both average 90 per cent. with the per cent. of loading in favor of the Harvard station.

As also tabulated in Table V., the test results show that 3.38 pounds of coal and 28.8 pounds of steam are required to develop 1 k.w. hour under the most favorable conditions. These values are somewhat higher than those reported for several street railway power stations in the *Street Railway Review* of February 15, 1898, September 15, 1899, and July 15, 1900. The data reported by the Metropolitan Elevated of Chicago show an economy varying from 2.19 to 5.78 pounds of fuel per k.w. hour. The

average of the reports, however, runs about 2.7 pounds of coal per k.w. hour. In these reports bituminous coal is specified whereas block coal of low grade is used at Anderson. In the test reported by E. P. Roberts & Co. made on October 5, 1901,* on the Dayton and Northern Traction Co'.s system it is specified that the engines developed an i.h.p. on 16.3 pounds of dry steam per hour and that one k.w. hour was developed on 3.7 pounds of coal per k.w. hour. The efficiency of the boiler and furnace was 65 per cent. Comparing these results with those of the Anderson

TABLE VI.

RESULTS OF TESTS GIVING MAXIMUM AND AVERAG LOADS, AND MAXIMUM VARIATIONS OF LOAD IN FIFTEEN MINUTES.

		April 17.		April 18.		April 19.	
		H.P.	K.W.	H.P	K.W.	H.P.	K.W.
Maximum load recorded	Engines indicated	3020	2250	3020	2250	3380	2520
	Dynamos: delivered	2620	1950	2820	2100	3100	2315
Average load	Engines: indicated	2140	1600	2060	1540	2465	1840
	Dynamos: delivered	1860	1390	1870	1385	2220	1660
Maximum variation of load recorded for 15 minutes	Engines: indicated	3020	2250	2550	1900	3020	2250
		2340	1750	1800	1350	2050	1530
	Dynamos. delivered	2550	1900	2340	1750	2810	2100
		1840	1375	1700	1275	1540	1150
Maximum variation as above in per cent.	Engines	29	29	41	41	47	47
	Dynamos	35	35	37	37	83	83

tests, the steam economy per i.h.p. is better, the coal economy per k.w. hour worse and the efficiency of the boilers less. The per cent. of loading of the engines is unfortunately not given. The engine economy reported by Roberts seems extremely good in view of the fact that the engines are of but 400 h.p. capacity. They are of the Buckeye type.

FRICTION TESTS.

Table VIII. gives the results of a special friction test of Engine No. 2 made on the morning of the 19th, after all cars had ceased running. Ten readings were taken after the operators in every

Street Railway Journal, September 6, 1902.

substation had been instructed to disconnect the direct current leads of the rotaries, leaving them running free. The power indicated then, included that used in engine friction, generator losses, transformer and transmission losses, and that required to run all the rotary converters in the system.

The operators were next telephoned to throw off the rotaries, leaving the transformers only on the line, and ten more readings were taken. The difference in the indicated power between these first two conditions is that required to run the rotaries.

The generator switches were then opened, and ten readings taken on "no load," with normal field excitation. The difference between the power indicated under conditions No. 2 and No. 3 is that lost in the transformers and in the high tension transmission lines.

TABLE VII.

ENGINE LOG.

ENGINE No. 1.	Cut in, 4:15 A. M., April 17.	Out, 1:30, April 18.	21¼ hours.
	Cut in, 4:30 A. M., April 19.	Out, 6:00 A. M., April 19	3½ hours.
	Total, 24¾ hours.		
ENGINE No. 2.	Cut in, 5:00 A. M., April 17.	Out, 7:00 A. M., April 17.	2 hours.
	Cut in, 5:00 A. M., April 18.	Out, 1:30 A. M., April 19.	20½ hours.
	Cut in, 6:15 A. M., April 19.	Out, 1:30 A. M., April 20.	19¼ hours.
	Total, 41¾ hours.		
ENGINE No. 3.	Cut in, 7:15 A. M., April 17.	Out, 11:30 P. M., April 17.	16¼ hours.
	Cut in, 4:15 A. M., April 18.	Out, 11:45 P. M., April 18.	19½ hours.
	Cut in, 5:00 A. M., April 19.	Out, 12:15 A. M., April 20.	19¼ hours.
	Total, 55 hours.		

Next, the field circuit of the generator was opened, and the engine ran free, ten readings being taken under these conditions. The power shown by this final set of readings is that consumed in overcoming the friction of the generating unit, and may be considered constant at all loads. The difference in the power under conditions No. 3 and No. 4 gives the hysteresis and eddy current losses.

The engine and generator friction loss of 64.2 horse-power is only 3.2 per cent. of the maximum capacity of the engine and only 5 per cent. of the average power developed by the engine during the test. Including, as it does, the friction in both engine and generator, this is a low value.

GENERAL PLANT EFFICIENCY.

In summing up and determining the general plant efficiency a method has been resorted to for reconciling the recording wattmeter readings with the instantaneous readings which it is

believed gives a correct adjustment between the indicated engine load and the generator load recorded by the integrating wattmeters. In Figs. 7, 8 and 9 the instantaneous i.h.p. and k.w. readings have been plotted against time and the ratio of the areas of these curves is proportional to the ratio of the total indicated power to the total power generated, on the assumption that variations in the load between plotted points follow the straight lines connecting the plotted points. As a matter of fact, during the 15 minute intervals between the plotted points of these curves, material variations take place in the load. These variations, which Figs. 7, 8 and 9 fail to record, are summed and included in the wattmeter readings. Consequently, to determine the correct value of the indicated

TABLE VIII.

SPECIAL TEST.

	H.P.	K.W
Average power developed under conditions No. 1	341.4 or	254.5
" " " " " " 2	199.4 or	148.8
" " " " " " 3	100.5 or	74.8
" " " " " " 4	64.2 or	47.9
Power required to run the rotaries	142.0 or	105.9
Power lost in transformers and transmission	98.9 or	74.0
Power lost in hysteresis and eddy currents	36.3 or	26.9
Friction loss in engine and generator	64.2 or	47.9

power of the engines, for comparison with the total output of the station as recorded by the recording wattmeter, the total indicated power as determined from the areas of the i.h.p. curves of Figs. 7, 8 and 9, must be mulitplied by the ratio of the k.w. hour outputs recorded by the recording wattmeter, to the areas of the k.w. curves of Figs. 7, 8 and 9. Following out this method, we find that the i.h.p. output as determined from the curve of Fig. 7 must be increased by 11.5 per cent. (see Item 11, Table 9) to be a true measure of the total indicated h.p. hours developed on that day. In the same manner an increase of 8.4 per cent. must be made for April 18 and of 6.9 per cent. for April 19th to bring the indicated h.p. hour values up to a point where they are correctly comparable with the k.w. hour output values determined from the recording wattmeters.

Table IX. contains a tabulation of the results which show the thermal efficiency of the plant. From this table we find that the

efficiency of the furnaces and boilers is 79.6 per cent., *i.e.*, 79.6 per cent. of the total heat in the coal as fired is delivered by the boilers to the engines in the steam. The average thermal efficiency of conversion between the boilers and the engine cylinders is 9.11 per cent., *i.e.*, 9.11 per cent. of all the heat delivered in steam by the boilers is converted into work in the cylinders of the main engines. This value of 9.11 per cent. credits against the engines the heat in the steam used in the auxiliaries. If we follow out the assumption that 15 per cent. of the steam delivered by the boilers is consumed by the auxiliaries, the thermal efficiency of the engines works out to be 10.7 per cent. The average thermal efficiency of the plant is 7.25 per cent. from the coal pile up to the engine cylinders and the average thermal

TABLE IX.

STATION EFFICIENCIES.

No	Quantity.	April 17.	April 18.	April 19.	Total.
1	Coal burned, pounds	144,500	145,000	146,000	435,500
2	Water evap. from 11.45° C.	1,229,700	1,244,400	1,244,400	3,717,500
3	Water evap. per lb. coal	8.51	8.58	8.52	8.53
4	Equiv. evap. per lb. coal	10.21	10.30	10.22	10.24
5	EFFICIENCY FURNACE AND BOILER	79.1	79.7	81.1	79.6
6	I.H.P. from area curve	51,300	48,000	55,000	153,820
7	THERMAL EFFICIENCY ENGINES	9.14	8.55	9.65	9.11
8	TOTAL THERMAL EFFICIENCY	7.23	6.82	7.82	7.25
9	K.W.H. from area curve	29,200	29,500	34,450	93,150
10	K.W.H. from wattmeter	33,000	32,200	36,700	101,900
11	Error (W.M. as standard)	11.5%	8.4%	6.9%	9.1%
12	Efficiency generating units, ratio areas	87.2	90.0	90.5	89.2
13	Efficiency generating units, average instantaneous efficiencies	86.1	89.4	89.1	88.2
14	TOTAL THERMAL EFFICIENCY	6.23	6.08	6.96	6.39

efficiency of the plant from the coal-pile to the switchboard, *i.e.*, the ratio of the energy delivered by the generators to the total heat in the coal, is 6.39 per cent. Although it is frequently stated that the thermal efficiency of the steam engine at a maximum is about 25 per cent., it is improbable that any engine of this class working under these conditions will convert more than 12 per cent. of the heat of the steam into work. The thermal efficiency of 6.39 per cent. up to and including the switchboard shows high economy as compared with other stations of a similar character.

The total thermal efficiency of the Harrison Street station of the Chicago Edison Company has been estimated to be 4.5 per cent., while the thermal efficiency of the generating station of the

Blue Island, Chicago Storage Battery Road was found to be 5.5 per cent*.

Items 12 and 13 of Table IX. give the efficiency of the generating units, *i.e.*, the ratio of the delivered electric power to the indicated power of the engines. Item 12 is the ratio of the k.w. and i.h.p. areas of the curves of Figs. 7, 8 and 9, while Item 13 is the average of the instantaneous ratios of the delivered electrical power to the indicated mechanical power. The two methods give—as they should—substantially the same values and are a check one upon the other.

The maximum power indicated by the engines is 3,380. This load came on April 19th at 5.45 P. M. The maximum variation in the load in fifteen minutes also occurred on April 19th but between 1.45 and 2 P. M., when the load changed from 3,020 to 2,050 h.p. This is a variation of 47 per cent. in the indicated power of

TABLE X.
Costs.

	April 17.	April 18.	April 19.	Total.
Cost coal per K.W.H.	$.00295	$.00304	$.00260	$.00288
K.W.H. per pound coal.	.229	.222	.251	.234
Cost coal to evaporate 1,000 pounds of water from and at 212°	$.0655	$.0651	$.0657	$.0654

the engines. The variation in the load during this time, as shown by the electrical instruments, is 83 per cent., which indicates that the engine fly wheels materially diminished the strain on the engine cylinders by bringing their stored energy into play. The greatest average load occurred on April 19th, and was 2,465 h.p.

The Anderson power plant of the Union Traction Company uses Indiana block coal in developing power. It is delivered at a cost of $1.35 per ton. On the basis of this figure, as shown in Table 10, the cost of developing a k.w. hour is $.0028. The cost of developing a k.w. hour may be taken as the final estimate of the efficiency of any station, as the aim and end is to develop as much power as possible per unit of cost. The fuel cost to develop a k.w. hour output varies materially in different stations. In the *Street Railway Review* articles already referred to, the cost in fuel

**Street Railway Review*, February 15, 1898, Test of the Chicago S. B. Road.

per k.w. hour varies from $.00246 to $.01016. The average of the best results, those reported in the *Street Railway Review* of July 15, 1900, is $.0045, an amount considerably larger than the cost economy shown by the Anderson station. Tests of the Oshkosh Street Railway plant, already referred to, show a k.w. hour to be developed at a fuel cost of $.01009. The test of the Chicago Storage Battery Road shows the fuel cost per net k.w. hour output to be $.00611, and the Chicago Edison is reported to develop a k.w. hour output at a cost of $.003. These figures are sufficient to show that the fuel cost economy of the Anderson station is extremely good and that the company is probably developing power at as low a figure as is possible under ordinary conditions of electric railway central station power development.

The thanks of the authors are especially due to Mr. A. S. Ritchie, electrical engineer, and Mr. A. J. Black, mechanical engineer, of the Union Traction Company, for their great assistance in facilitating all the arrangements for the tests and in materially promoting their successful outcome.

Discussion.

Professor Goldsborough:—I have here another Chart A, which shows the ultimate efficiency of the plant in terms of the total power delivered to the cars. We see, then, that the station

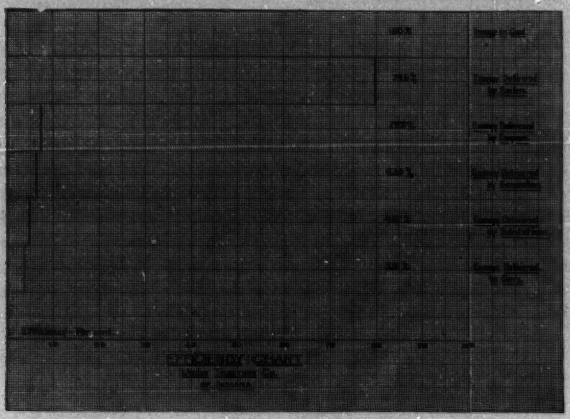


Chart A—Part 1

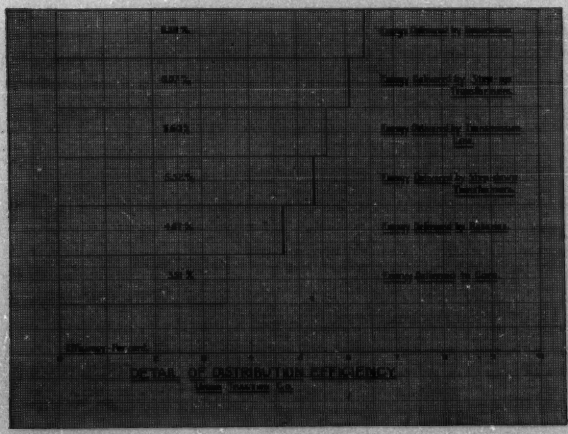


Chart A—Part 2.

delivers to the line 6.39 per cent. of the total energy of the coal, and there is 3.51 per cent. only of the total energy of the coal that ever gets to the cars.

MR. GERRY:—I would like to ask a question in reference to the figures given; the speaker states the efficiency of generation as 12.63 per cent., and I understood him to say the total efficiency was 3.65 per cent. To what does the last figure apply? Where was the power delivered at the efficiency stated?

PROFESSOR GOLDSBOROUGH:—The last figure applies to the power which was delivered to the cars, and this power was determined by having indicating wattmeters on all of the cars, so that we got the actual power delivered to the cars from the generating station; to the car, not to the axle.

MR. GERRY:—That represents about 50 per cent. efficiency between the station and the power delivered to the car?

PROFESSOR GOLDSBOROUGH:—Yes; the efficiency of the high-tension transmission system is about 74 per cent. That is, including the raising transformers, high-tension wires, depressing transformers, and the rotaries; and about 75 per cent. for the low-tension network. So that you get a loss, as you suggest, of about 55 per cent. all told.

MR. GERRY:—Yes; less than 50 per cent. That is rather large, and it would be interesting to know the result if everything were included between the electrical output of the station, and the mechanical output of the cars. It would reduce the total efficiency of the plant at the car-axle by certainly 25 per cent. or 30 per cent., making the total efficiency of the installation around 2½ per cent.

PROFESSOR GOLDSBOROUGH:—I think that is a fair assumption. Now, we must remember that in this particular system the cost of copper has been made as low as possible. Power is developed so cheaply that power is about the cheapest thing they have. In other words, one passenger per car comes pretty near paying the cost of the power used by that car from Indianapolis to Muncie, and they only charge one cent a mile.

MR. GERRY:—Then this plant is not presented as an example of a high efficiency, or even of average efficiency, as far as power is concerned. The point I was intending to bring out was, that the efficiency of transmission was low, very low. I have not read the Professor's paper, and may not understand the situation fully, but I understood this plant was presented as an example of one of fair, or high efficiency, but we have here in the transmission an indication of a very low efficiency.

PROFESSOR GOLDSBOROUGH:—I look at the matter in this way—we have here a series of tests upon a very highly efficient inter-urban property. But how are we to gauge or determine its efficiency? Are we to gauge it on the basis of efficiency in terms of power conversion or on the basis of efficiency in terms of its paying capacity? Now, it has a very high financial efficiency; it makes a good return on the investment. Every element

which enters into the station is sufficiently large and properly installed to meet all emergencies. It is a safe property so far as its ability to operate continuously is concerned. When it comes to determining whether you shall put more or less copper into the distributing system, you have to go right about finding out what coal costs you, what the interest cost on your investment is, and what the operating cost of your system is. These elements must be made to bear a proper relation to each other. You should not put capital into large feeders and appliances to make the efficiency of distribution high when by so doing you create an interest cost greater than the value of the power thereby saved. I think that we should consider this plant as being a measure of what engineers, after careful analysis of the problem, have determined upon as most fit to promote the best economy in the operation of an interurban system. And it is just as vital for us to know that we should have a 50 per cent. distribution to obtain this economy as it would be for us to know that we must have a 99 per cent. efficiency to obtain it.

MR. GERRY:—I think Professor Goldsborough does not meet my point exactly. I do not know of any reason why you should put in a high efficiency station to make cheaper power, and then put in a low efficiency distributing system so as to waste the power afterwards. If you can produce power cheaply, and want to keep down the first cost of the station, put in a moderate class system all the way through. I desired to find out whether this was a high-class station and low-class distribution, and if so, why?

PROFESSOR GOLDSBOROUGH:—I think the matter can be answered very well in this way. We are confronted by a problem, we are required to deliver a certain minimum amount of power to certain cars continuously and as cheaply as possible. Now, if we put in a low-class generating station, low-class transformers, low-class rotaries, low-class storage batteries, we will not be able to meet the conditions. Now, if we have high-class generators, transformers, rotaries and all intermediate machinery, we are in a condition to render reliable service; this must be done anyway, regardless of the copper used. Any man who builds a station and puts in a second class engine, is doing himself and all of the people depending upon him an injustice. He must have the best there is in that particular element to secure the permanency of the plant. Now, when it comes to the question as to where his losses shall take place—he can get a good engine for the same money that he would pay for a poor one; he can get a good dynamo on about the same basis; and there is no excuse for putting in bad machinery. In the case of his copper conductors, however, it is another matter. Copper is copper, much or little, and in it should occur "the loss" in interurban work if the low cost of fuel warrants any excessive power loss at all. As long as conductors are strong enough and do not heat excessively, they are reliable elements in the system;

and whether they are small or large is unimportant so long as their cost is properly adjusted to the earning capacity of the plant as a whole. They are now using 16,000 volts. In the system they are putting into Logansport they are going to use 32,000. Maybe some day instead of operating the cars with direct current at 500 volts, they will operate with alternating current at 10,000. They may be able to operate a system of twice the size with the same generating plant. That is one of the things they are thinking about, to see if this plant, which is now able to operate only 100 miles of road cannot be made to operate 200 miles, not by increasing the total cross-section of the copper but by decreasing the total cross-section of the copper and increasing the depression.

MR. GERRY:—Then the high efficiency is a matter for the future. I hope the Professor will not understand me as advocating the undesirable types of machinery which he indicates. There is a real difference, however, between high and low-efficiency machinery, not only in its economy, but in the first cost; in other words, you can obtain very excellent steam and other machinery if you are willing to content yourself with a little lower efficiency, and such machinery is really excellent for service, and there are many places where it should go in. It will give good results, practical results, but still, it is not the highest efficiency machinery. In fact, the highest-efficiency machinery does not always give the best operating results; but where the costs of labor and fuel are high, then efficiency becomes of importance, and we go to the extremes of cost and refinement to obtain the best results in that direction. I was simply trying to settle the question whether this was a case for such refinements, and if so, why the efficiency was afterwards sacrificed in the transmission system.

MR. STOTT:—The ultimate object in any power plant, it seems to me, is to place the kilowatt hour on the receiving apparatus at a minimum cost, and there is no other object in a power plant, so far as I know. You have to take into consideration, first, the cost of coal. If the coal is going to be a very high item, you must put in an extremely efficient plant, and put in all the accessories, such as economizers, feed-water heaters, etc. If your coal is a very cheap item you can afford to sacrifice a great deal and reduce the interest charges on the plant. But in the end you must consider the whole problem; viz., what you expect to deliver the kilowatt hour at the receiving apparatus for. Now, in this paper we have not been given the total cost of the power delivered, as I understand it. I may not have read the paper carefully enough. This is only the fuel cost that is given, is that right? The total cost as it is delivered at the car is the real test. While the cost as shown here in coal is extremely low, yet it may be a great deal higher when delivered at the car than in a great many other plants. In New York the proportion that the cost of coal bears to the total cost is about 70 per cent.

There of course we must have an extremely efficient distributing system as well as power plant, and every thing you can do to reduce the amount of coal is justifiable. The efficiency from the generator to the engine. This constant which is introduced by a comparison of the various indicated wattmeter curves with recorded wattmeter curves, is something entirely new, and I think makes comparison rather unfair to plants whose efficiency has been calculated merely upon the basis of indicated horse-power to kilowatt output; and to make the comparison perfectly fair other plants should have this factor introduced as well as a factor covering the difference in load-factor. If Professor Goldsborough can give any information upon the question of total cost delivered at the car, I think it will make the paper a great deal more complete.

MR. DUNN:—It is a fact that "cost" is one of the most loosely used terms in electrical nomenclature. When I see it I hesitate to pay attention to the figures given because there is so seldom any definition of what they include. I wish it were possible for us to get the idea that we should never use the word "cost" without saying what cost we mean. I wish also that it were possible that costs presented before the INSTITUTE, for statistics should never be given unless they included interest charges, taxes, depreciations, charges for sinking funds, and every other item, so that we should have before us when we were considering cost figures everything except dividends. Our statistics on the cost of power are of little use because of this lack of definiteness in specifying what we include when we say "cost."

MR. WELLS:—I notice that Professor Goldsborough's estimate of moisture in the coal was 6 per cent. I would say that in 77 analyses made on eight different grades of bituminous coal, the moisture varied from 1.15 to 5.25, or an average of about 3 per cent. for all the different grades, and that the calorific value of these coals varied from 12,967 B.T.U. to 14,041 B.T.U.

MR. LINCOLN:—The question which Mr. Gerry raised in regard to Professor Goldsborough's paper seems to be simply a question of Kelvin's law. He can develop his power for a certain amount at the station, and it is a question of a well-known law how much of that shall be lost in his line. If his power is cheap he can afford to lose more power in his line than if the power costs more. It is for the engineer to determine whether he shall put money or energy into his line.

PROFESSOR GOLDSBOROUGH:—The reason that no more figures are given than have been given of cost has been stated by the other speakers. We took that matter up, and had it been carried out to the point that we wished there would not have been anything else to say. The whole story would have been told. Everybody who has any idea of buying or selling stock would have been given ideas regarding the plant which possibly the directors would not care that they should have. I have made a number of tests on plants and have worked down through the

financial side as well as the engineering side of the problems, but I have never yet had the consent of directors to my publishing that part of a report which deals with the finances of the plant, further than the part that covers the ordinary operating expenses. I have not gone further than I have for the reason that when I give you the cost of a kilowatt-hour in terms of the cost of the coal, I give you something that is perfectly definite; everybody knows what I mean. If I should give you other figures you would immediately want to know what they included. I may say, however, that the cost of manufacturing power in this plant is about one-half cent a kilowatt-hour. This figure does not include any of the items which Mr. Dunn has said ought to be included.

As regards this particular plant, you will notice, by the floor plan of the building, that room is allowed for two or three more units, although objection was made to the fact that I pointed to the future in discussing why good machinery was put into this plant. It is expected that the plant is not to be a present-day matter. It is in a place where coal is cheap, it is in a region where the population is well distributed and is large, and where people are in the habit of traveling. The system is expected to grow; and already it is double the size it was when this test was made.

Now, as regards moisture in the coal. The coal in this particular station is kept over the boilers. A sufficient supply of coal is placed there so that the coal becomes pretty thoroughly dried out before it is fed into the furnaces. As the station is ordinarily operated, the coal is never handled by hand; when received it is dumped into the station, conveyors carry it around, ashes are taken out, and you wouldn't know there was any coal except that you see the little that runs out from the chutes into the furnaces. There are only two men in the boiler room of the station.

We took samples of coal regularly by the most approved method, separating it all out, etc., and then put it in cans and put tops on these cans. But it so happened that we could not get the cans soldered up for three or four hours, and during that time the coal was subjected to different conditions of moisture in the atmosphere. When we tested our coal finally, by chemical analysis, etc., we found we couldn't rely upon the results. We had to go back to the point of approximating, not because our work was inaccurate, but because we did not believe it represented all the conditions of operation in the plant. We took six per cent. as the result of a general inspection and a review of other printed results showing the use of the same coal.

PRESIDENT SCOTT:—We will now turn to another subject, "The Electrical Equipment of a Gold Dredge," by R. L. Montague.

Paper read by Mr. Gerry.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

THE ELECTRICAL EQUIPMENT OF A GOLD DREDGE.

BY RALPH L. MONTAGU.

Before describing the electrical equipment, it would be well, perhaps, to say a few words relating to the use and object of a gold dredge.

The occurrence of gold in deposits of gravel is caused by the action of some river or glacier which in its course has broken up and carried along in the form of gravel the rock that formed the boundary of its channel.

When gold-bearing veins exist in this rock, the gold, in the course of time, becomes freed from its surrounding ore, and is together with the gravel already formed deposited at some point where the velocity of the water ceases to be high enough to keep the gravel in motion.

Placer mining is the name by which the process of extracting the gold thus deposited from its surrounding gravel, is known. Briefly, it consists of feeding gravel and water into a rectangular trough (sluice box), set on a grade, on the bottom of which depressions or hollow spaces (riffles) are provided. The gold, owing to its high specific gravity, settles in these depressions while the gravel is carried on down the sluice and dumped at the end.

To accomplish this process on a large scale, there must be sufficient grade to the deposit of gravel and its underlying bed rock to prevent the worked-out gravel (tailings) from interfering with the excavating operations which are feeding the gravel into the sluice.

Where the natural grade is not sufficient for this purpose, a

grade must be produced by artificial means. Until dredging was applied for this purpose the method known as hydraulic mining was used. It consisted of sinking a pit to bed rock, the gravel being lifted into a sluice box supported on a trestle by an hydraulic elevator. The most common way of breaking down the banks of gravel was by the use of a stream of water under a high head (hydraulic giant) directed against the face of the bank. But in localities where sufficient water could not be obtained for hydraulic mining, except at a prohibitive expense, the deposits have not been considered of any value until the advent of the gold dredge. Furthermore, where sufficient water was available to work the deposit by the hydraulic method, the same water if applied to turbines for the generation of electric power to be used to drive dredges, would handle from two to two and a half times more gravel.

Fig. 1 gives in outline a type of gold dredge. The excavating is done by the endless chain of buckets, which revolving round the upper tumbler, dumps the gravel into a revolving screen (termed a *grizzly*). Jets of water play on the gravel and thoroughly wash it; the fine gravel and gold fall through the openings in the grizzly into a sump, from whence it is picked up together with sufficient water and elevated into the sluice box. The coarse gravel, large stones, etc., are allowed to fall overboard, being of no value. The gold, as already described, is recovered in the riffles forming the bottom of the sluice; the washed gravel carrying practically no values, falls over the lower end of the sluice and fills up the cut that was previously made by the dredge. The dredge is held in position by the anchor or spud at the stern, and side lines from the bow permit the buckets to be freed across the face of the cut. There are two spuds on a dredge; one is used for holding the dredge and the other is used when a cut is completed and it becomes necessary to step the dredge ahead. With this type of dredge it is possible to handle .85 cubic yards of gravel per h.p. hour delivered on board.

The various pieces of machinery, together with their respective motors, may be summarized as follows:

The endless chain of buckets driven by a variable speed reversible motor; the revolving screen, together with a small pump for furnishing the jets of water, driven by a constant speed motor; the large centrifugal pump for elevating water and gravel into the sluice, driven by a constant speed motor; the winch which revolves drums to which are attached the side lines, lines for

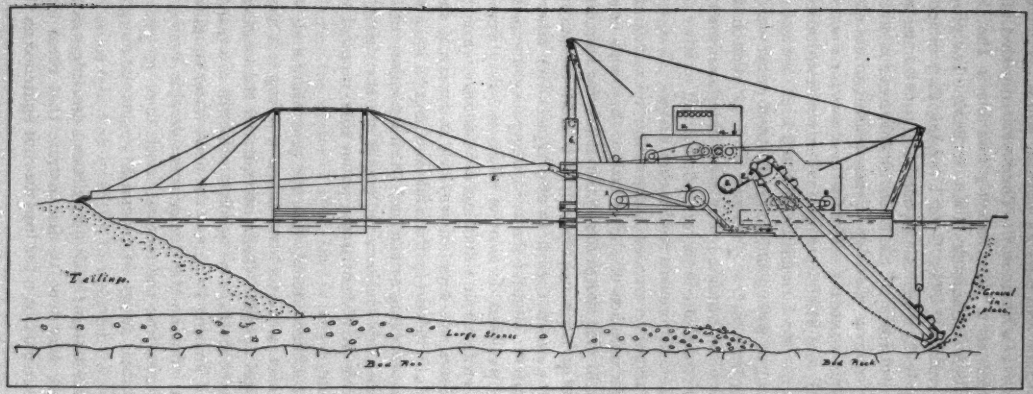


FIG. 1.

1. Buckets excavating gravel.
2. Buckets dumping gravel.
3. Revolving screen.
4. Centrifugal pump.
5. Sluice box.
6. Spud or anchor.
7. Winch.
8. Bucket driver motor var. speed.
9. Pump driver motor const. speed.
10. Winch motor var. speed.
11. Switchboard.
12. Pilot house and operating trusses.

hoisting bucket chain and lines for hoisting spuds, is driven by a variable speed reversible motor. The first dredge that made a commercial success as a placer mining machine in the United States was installed at Bannack, Mont., in 1895. The property owned by the company (The Gold Dredging Co.) included a water-right and ditch, which if extended about two miles would give a head of 340 feet. As the water at this head would give sufficient power to drive a dredge it was decided to use electric power in preference to steam. The fuel cost was for wood $4.50 per cord and for coal $12.00 per ton. The writer installed the electric equipment, which consisted of a 100 k.w., 500 volts d.c. generator, running at 650 r.p.m., and four street railway motors.

The generator was direct connected to a 26″ Pelton water wheel, by means of an insulated coupling. The power was transmitted over 000 stranded conductors, triple braid weather proof, from the pole line on shore to a reel on the dredge. Two of the motors were mounted on wooden bases sliding on rails and had overhung pulleys in place of the pinions; they were used to operate the winch. One motor drove the drums for hoisting the spuds and the other motor operated the balance of the winch. The controllers were of the rheostatic type. The other two motors were geared to counter-shafts having pulleys mounted on them, the whole mounted on wooden bases, and they were controlled by d.p. switches and starting resistances of iron wire; one of these motors was supplied with a d.p. reversing switch. This motor had to drive (1) the endless chain of excavating buckets, (2) the revolving screen and (3) a secondary chain of buckets, which elevated the screened gravel into the sluice. The other motor drove a 10″ centrifugal pump that supplied water to the sluice box.

No trouble was encountered with the generating end of the plant, with the exception of a little difficulty owing to a mistake in the water-wheel design, which necessitated the lengthening of the water-wheel shaft, so as to allow sufficient clearance between wheel and housing to permit the dead water to fall away from the wheel; but on the dredge, considerable trouble was experienced in operating the motors. Both these motors were overloaded and their design in general left plenty of margin for improvement.

During the first season (1895) very little excavating was done, but enough work was done to demonstrate that these motors would not give satisfaction if the load was not lightened on them;

accordingly, during the interval between the seasons of 1895 and 1896, the motor driving the 10″ centrifugal pump was replaced by a shunt wound motor and the load of the other railway motor was divided between it and the motor taken off the pump. One motor drove the bucket chain (1) and the other, the grizzly and secondary chain. Mechanical changes were effected at the same time, which permitted the almost continuous operation of the dredge during the season of 1896. As the motors now were running on an average of 23 hours per day, there were plenty of opportunities for the weak spots to develop. The motor driving the bucket chain (excavating) burnt out an armature on an average every thirty days. The ends of the commutators next to the bearing on these motors were constantly getting grounded, the brushholders were overheated and brushholder springs lost their vitality. By keeping two or three extra armatures on hand, no time was lost on armature account; but on one occasion the lower field coil of the motor that drove the grizzly became badly grounded, and short-circuited. As we had no spare field coils on hand I unwound the coil, rewinding the wire on a barrel, and after painting the interior of the field bobbin with insulating paint, I rewound the coil with the old wire, painting the wire as it was laid on. From my recollection, I should say the wire was about 000 solid, and anybody who has had to rewind a magnet coil with previously used wire of this size and with practically no appliances, such as sheaves for wire to run over, need not be told that I did not get back on the field-bobbin all the wire that came off; however, I got back enough to answer the purpose and within 10 hours from the time of the accident the dredge was in operation again, and the motor lasted to the end of that season.

During the winter of 1896–1897 it was decided to discontinue the use of the secondary chain of buckets for elevating the screened gravel into the sluice, and to use a centrifugal pump of sufficient size to lift this gravel and the necessary water for sluicing it. The new arrangement presented an outline similar to that in Fig. 1.

The experiences met with in this the first successful application of a dredge to placer mining in America have been described at considerable length, because this plant was the forerunner of numerous others in localities throughout the mining districts of North and South America, which have created a new demand for

labor and opened a field for the investment of millions of dollars.[1]

I will now endeavor to describe the nature of the loads on the various motors. That on the motor that drives the bucket chain is a peculiar one; it may be described as a combination of an elevator load and a street car load, but with many less stops and no particular need for very rapid acceleration. When beginning a cut at the surface, the incline up which the buckets travel may be only 20° from the horizontal, the soil as a rule is very loose and the starting torque is, comparatively speaking, nominal. The motor has only to overcome the inertia due to the mass and weight of bucket chain, viz., from 250 to 400 lbs. per foot of length. As the buckets become loaded with gravel, the load increases. The speed of the bucket chain at the top of the cut can be as high as 60 feet per minute with safety. This load is similar to an elevator load and is steady; the only fluctuations being caused by a bucket as it revolves round the lower tumbler, taking an extra large bite out of the gravel or missing the gravel and merely bailing water. As the depth of the cut increases, the load increases on the motor because the angle between incline of chain and horizon is greater; and if a series wound d.c. motor is used some resistance should be cut out, if it is still safe to maintain the high speed. When a certain depth is reached and the gravel becomes coarser, is packed harder and large boulders are liable to be met with, the speed should be reduced by cutting in resistance; finally, when close to bed-rock, the speed should be still further reduced; the buckets should not now exceed a speed of 40 feet a minute; and in actually scraping bed-rock the speed should be still further reduced. The buckets are now nearly empty of gravel; the incline is about 45° with the horizon, and it will be necessary to cut in all available resistance into the circuit of a d.c. series or into the secondary of an induction motor. The construction of this resistance should be such as to permit its being kept continuously in the circuit, as in some fields it is necessary to keep up the scraping of bed rock for several hours because the majority of the gold values are obtained on or near bed rock.

During this, the most important part of the excavation of a cut, the motor is running with a low efficiency; and it

1. At this point (Oroville, Cal.,) there are in operation and building over 20 dredges; each dredge has cost at least $50,000; and the ground to be mined previously worth from $2 to $10 per acre, sells now as high as $1,500 per acre

may be asked why a two speed gearing should not be introduced so that the motor would operate efficiently at the low bucket speed. In one case, to my knowledge, a two-speed gear was tried, but finally discarded, because it did not give such general satisfaction as the arrangement at present in almost universal use, viz., a d.c. series-wound motor with rheostatic control or an induction motor with a variable resistance in secondary or rotor circuit.

I have not yet mentioned the condition when the most severe load is thrown on the motor, that is when the motor is stalled. At some point in the train of gears that reduces the high speed of the motor to the low speed of the top or driving tumbler (2.75 – 5 r.p.m.) an adjustable slipping-friction is placed and set so that it will slip before the circuit-breaker or fuses open the motor circuit. The buckets may encounter an extra large boulder, a submerged timber or stump or the bank may cave down and completely bury them. Let us suppose the buckets are running at a speed of 45 feet per minute when an obstruction is met that causes the friction so slip. The motor is stopped and when it has come to rest it should be allowed to run back so as to let a little slack into the bucket chain. Sometimes it is necessary to reverse the bucket chain one bucket or link length. On restarting the motor the obstruction may be removed, sometimes, however, it is necessary to stop and start a number of times before this is accomplished; it may be necessary to tighten the friction or hold the circiut breaker from opening, but whatever the nature of the obstruction, it must be overcome because if boulders are not dug out and disposed of they will be liable to form an effective barrier between the buckets and bed-rock, which will mean that a large proportion of the gold contained in the cut is not recovered.

Sometimes it is necessary to stop the buckets, which may be running at full speed, in two or three seconds of time; the only way to do this is to reverse the motor. Therefore, it will be seen that the motor that drives the bucket-chain should be capable of withstanding considerable strains, both mechanical and electrical. I have seen a d.c. series wound motor (500 v.) the normal current of which was 40–60 amperes, take over 200 amperes, while picking up a particularly large boulder; and a 3-phase, 1000 v. induction motor, normal load 25 amps. per phase with secondary short-circuited, has taken

95 amps. per phase, while the buckets were being released from an extra large cave-down of gravel.

The periods of these abnormal loads are limited, rarely exceeding a full minute. While not attempting to deduce an exact formula for determining the necessary rated h.p. of a motor for this class of work, I will state that calculations can be based on the fact that a 50 h.p. motor should be installed to drive a chain composed of alternate buckets and links, the bucket capacity being 5 cubic feet each, built of good mechanical proportions and capable of reaching a maximum depth below water level of 35 feet, the top or driving tumbler being suspended about 14 feet above water level. In actual work the incline up which the buckets travel does not exceed an angle of 45° with the horizon.

Passing on to the motor that drives the grizzly and small centrifugal pump, very little need be said about it; the load and speed are constant and in starting the load is light as the centrifugal pump does not begin to pick up water until nearly full-speed is reached. A shunt d.c. or induction motor, squirrel cage type, of 30 h.p. is generally used for this load, *i.e.*, where the grizzly and pump are proportioned to screen and wash the gravel excavated by the 5 foot bucket chain.

The same remarks about load and power required to start apply to the motor that drives the large (12″) centrifugal pump that elevates water and gravel into the sluice; the h.p. of the motor can be found from the following formula:

$$\text{h.p. of motor} = \frac{(\text{diam. of discharge in inches})^2 \times \text{feet lift}}{2 \times 20}$$

A little difficulty may be experienced in finding the exact diameter of motor pulley. There is a certain critical speed at which to run a centrifugal pump that lifts water and gravel; a reduction of 10 per cent. below this speed reduces the velocity of the water to a point where it is unable to pick up gravel; 10 per cent. above the critical speed calls for an increase of power out of all proportion to the increase of speed of the pump, besides which the resultant velocity of the water in the sluice-box may be so high as to prevent the gold from being deposited in the riffles.

There are some peculiar facts concerning the operation of centrifugal pumps by constant speed motors.* If such a centrifugal pump is lifting water to a certain height and the motor is fully loaded, a reduction of the head increases the load on the motor

and *vice versa*. This statement may seem to be contrary to all laws regarding the conservation of energy; but the peripheral speed of a centrifugal pump is in proportion to the square-root of the height to which the water has to be lifted[1]; furthermore, the volume of water lifted is not in direct proportion to the speed. If x be the speed of a pump (running efficiently) and y = power used to elevate 1000 gallons at any head; if x is reduced to $x/2$, $y = 0$ (not taking into consideration the losses due to friction), and no water is moved. When the speed is increased above x, the amount of water lifted does not keep up in proportion to increased speed. There is more slip in the water moved by the runner or piston and the efficiency begins to fall off enormously therefore, if we consider the original statement, we see that with a motor fully loaded and pump running at an efficient speed for a head of y feet; reducing y while moving more water, we do so at a very much lower efficiency and consequently overload the motor, provided the speed remains nearly constant.

The last motor to be considered is that which drives the winch used for swinging the dredge, hoisting bucket-chain, etc. The heaviest load this motor has is when the bucket-chain is being raised, the nature of which is similar to that thrown on an elevator motor. In raising the spuds or anchors, there is always some slack in the lines and full torque is not required in starting. In pulling on the side lines very little power is called for, but the speed variations required are beyond the scope of any motor. For instance, in digging off the top soil, the speed of the buckets across the face of the cut may be 20 feet a minute or more; when bed rock is reached, the speed may be as low as 5 feet a minute. When moving ahead and the buckets are not touching the gravel, the speed should be as high as possible, viz., 100 feet a minute or more. In general, the motor is geared to the winch, so as to produce the maximum speed, and the variations are produced by constantly starting and stopping the flow of current to the motor; this may seem to be hard on the controller, but the modern types of controller seem to stand this work remarkably well.

In some more recent winches a two-speed gearing has been adopted and this makes it easier for the controller. The only operation that it is necessary to consider when determining the maximum h.p. of the winch-motor is the hoisting of the bucket

1. The most efficient or critical peripheral speed of centrifugal pump in feet per minute

$$= \sqrt{\text{head in feet}} \times 8 \times 60$$

chain and the speed at which it is to be hoisted. All other loads that may be thrown on this motor are less than this load.

The current is taken aboard a dredge nowadays by means of an armored cable attached to a temporary pole line on shore; the slack cable is coiled up on the bank and as long as no heavy traffic passes over it and it is not covered up by the tailings, no trouble need be expected.

At Bannack, Mont., the writer designed a reel (Fig. 2) that was placed on the upper deck and the wires (000 stranded weather-proof insulation) ran over hard-wood sheaves and then swung onto the pole line. This class of wire had to be kept out of the water and off the ground. The object of the reel was to make it possible to take up slack or pay it out without stopping the operation of the dredge. This reel was exposed to the weather, but no leakage was ever apparent.

Where the current is brought aboard at moderately high voltages and it is necessary to use step-down transformers, these should on no account be anywhere except in a special deck house on the upper deck. The low voltage secondaries should be led to the pilot house, where a switchboard should be located, having a separate panel for each motor; on these panels there should be an ammeter s.p. switch and fuses or circuit-breakers, also a name plate designating the motor circuit to which these devices belong. The panel that has the main switch on it should have a voltmeter and v.m. switch, also the primary switch and fuses for the light transformer. On the light circuit there should be a voltmeter and the terminal board of a regulating device for raising or lowering the voltage of the light circuits. The individual light circuit switches should be named thus: "Port bow lights," "Starboard bow lights," etc.

The voltage of the motors should not exceed 400 a.c. or 500 d.c. There is no advantage to be gained in high voltage, as the leads from switchboard to motor never exceed 100 feet in length. The controllers for the bucket-drive motor and winch motor are located in the pilot house; the auto-starters for the other motors should be placed near the motors and the machinery they control. There should also be a complete system of push buttons and signal bells. Incandescent lamps are used almost exclusively; arc lamps give trouble owing to the constant vibration of the dredge. Fig. 3 is a diagram of the wiring of a dredge where the current was brought aboard at 1000 v. The power company supplied transformers for motors of 30 h.p. and

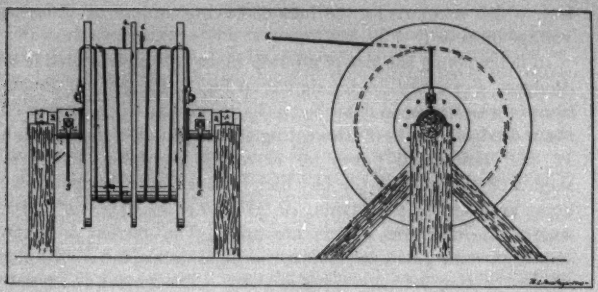


Fig. 2.

1. Strap to hold shaft.
2. Insulated sleeve.
3. Hard wood shaft (does not revolve.)
4. Insulated hub.
5. Wires to center of dist.
6. Wires to pole line as shown.

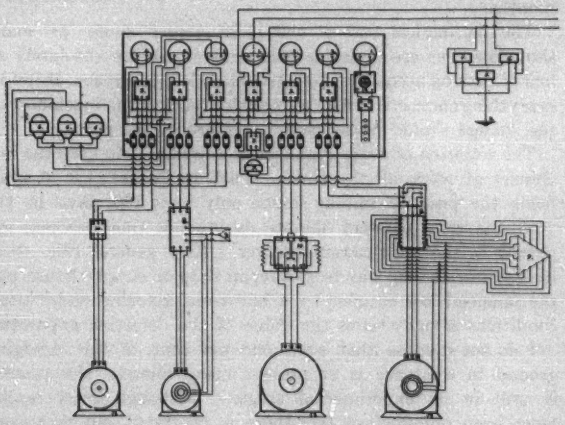


FIG. 3.

1. Voltmeters.
2. Ammeters.
3. Switches.
4. Fuse Blocks.
5. Lightning arresters.
6. Transformers, 1000–400.
7. Transformers, 1000–110.
8. Controllers for var. speed motors.
9. Resistance.
10. Auto starter.
11. Ground connection.
12. Const. speed motor.
13. Var. speed motors.
14. Regulator for lamp circuits.

less, which accounts for the fact of having motors of different voltage on board.

In determining the size of a power plant to supply a dredge or dredges. For every dredge similar to Fig. 1, the general dimensions of which may be described as being a 5-foot open-connected chain-dredge capable of excavating to a depth of 35 feet, with a 12 inch centrifugal pump for elevating purposes, 135 k.w. should be available at the bus bars on board the dredge for 24 hours per day for d.c. plants, or 170 k.v.a. at .80 power factor where a.c. induction motors are used. The current is taken aboard in some places at 4000 volts. I believe about 5000 volts will be the limit for a few years anyway. The motors and resistances should be such that they will be able to run continuously, without the least danger of overheating. The average running time on the Banack dredge was 23½ hours out of 24. In localities where the mining season is short, owing to severe winters, the usual practice is to run every day and night, Sundays and holidays included, the machinery being overhauled during the winter months.

The mechanical end of the plant causes quite as many shut-downs as are desirable and there should be absolutely no loss of time on account of defective electrical apparatus; therefore everything connected with the electrical part of the machinery on the dredge should be as near "fool-proof" as possible.

The ambition of every manager of a dredge is to keep the machinery at work all the time. When we realize that in some fields the possible mining season only lasts 150 days in the year, the value of every minute during this time becomes apparent to the most casual observer. As a general rule, these localities are a long way from a repair shop or supply house and the financial loss entailed by a burnt-out machine under these conditions is many times the value of the defective apparatus.

I do not suppose that even one per cent. of the dredging ground in existence is at present being mined; the process is still in its experimental stage. Although good results have been obtained so far, there is no doubt but that more advanced methods, both mechanical and electrical, will be discovered in the future to increase the efficiency of a process which is adding to the wealth of the world gold that would otherwise have remained in the ground where nature had placed it, viz.—gold dredging.

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Discussion.

President Scott:—The management of the Louisiana Purchase Exposition has appointed a general advisory committee on Electrical Congress. At the head of that committee is Professor Elihu Thomson and Doctor Kennelly is secretary. A meeting of the committee was held yesterday afternoon for preliminary work, and we should be pleased now to have a statement from Doctor Kennelly with respect to the work which is under way.

Doctor Kennelly:—As stated by the President, a preliminary meeting of the advisory committee was held yesterday. It was unanimously voted at the meeting that an International Electrical Congress should be held at St. Louis next year in conjunction with the St. Louis International Exposition. It was also the opinion of the advisory committee that delegates from foreign countries should be invited by the United States Government to attend the International Electrical Congress, as at the Chicago World's Fair Congress in 1893, and as at the International Paris Congress of 1900, for the purpose of debating and fixing any questions which might naturally call for the attention of such a Congress. The further scope and purposes of the proposed Congress were not entered into. They were left for consideration at some future time.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

THE LEGALIZED STANDARD OF ELECTROMOTIVE FORCE

BY HENRY S. CARHART.

It is not necessary to enlarge upon the importance of a legal standard of electromotive force. It is quite as essential as a legal standard of resistance.

It will be remembered that the Chamber of Delegates of the International Congress of Electricians at Chicago in 1893 adopted a value for the electromotive force of the Clark cell and appointed a committee to prepare a specification for its construction. The committee consisted of Prof. Helmholtz of Berlin, Prof. Ayrton, of London, and the writer. Unfortunately, before the committee reached an agreement, the eminent chairman died; the two remaining members being unable to agree, one form of cell was accordingly adopted by the British government, and another by the Congress of the United States. The latter represents the survival of the fittest, for reasons that were assigned in 1893.

Germany contented itself by legalizing the units of resistance and current.

The legal value of the electromotive force of the Clark cell is 1.434 international volts at 15° C. In the ten years which have intervened since the Chicago Congress, it has become quite certain that the actual electromotive force of the Clark cell at 15° C. is nearer 1.433 than 1.434. Indeed, the Helmholtz absolute electrodynamometer at the Reichsanstalt, gave in the hands of Dr. Kahle, 1.4322 volts. This value has not been used at all, but for the past six or seven years 1.4328 at 15° C. has been used at the Reichsanstalt. This value was not obtained by means of absolute measurements but by the silver voltameter, corrected by reference to the measured ratio between the electromotive

forces of the Clark and cadmium cells[1]. But the electrochemical equivalent of silver is not known with any greater accuracy, to say the least, than the electromotive force of the Clark cell. Hence, the Reichsanstalt method is open to grave objections.

In 1899 an absolute determination of the electromotive force of the Clark cell was made by the writer and Dr. Guthe[2]. The result was 1.4333 at 15° C We have never regarded this value as final, because certain changes in the dimensions of our absolute electrodynamometer did not permit us to repeat the measurements a sufficient number of times to get a satisfactory series.

Later Dr. Barnes of McGill University made a series of determinations of the mechanical equivalent of heat in terms of the international electrical units. His results will agree with those of Reynolds and Moorby, made by a purely mechanical method, if the electromotive force of the Clark cell is 1.43325 at 15° C.; and they will agree with Rowlands if the Clark is 1.43355[3].

During the past year we have again taken up the matter with the purpose of measuring the electromotive force of the Weston cadmium cell and the electrochemical equivalent of silver. The Weston cell, with a saturated solution and excess of cadmium sulphate crystals, is chosen because of its low temperature coefficient and the close agreement between the different cells of a series. The temperature coefficient of this cell has been so carefully determined at the Reichsanstalt that it is not necessary to repeat that part of the work. For cadmium cells with saturated solutions and an excess of cadmium sulphate crystals, the formula for the electromotive force at any temperature between about 10° C. and 30° C., is

$$Et = E_{20} - 0.000038\,(t-20) - 0.00000065\,(t-20)^3.$$

Further, the ratio, Clark 15°, cadmium 20°, has been determined at the Reichsanstalt in several series of comparisons with the greatest care and the most refined precautions. In one of these series the writer assisted. Giving due weights to the several series, the result is as follows:

$$\frac{\text{Clark at } 15^\circ}{\text{Cadmium at } 20^\circ} = 1.40670$$

An absolute determination of the electromotive force of the cadmium cell is therefore one also of the Clark cell, for the

1. *Phys. Rev.*, Vol. XII, No. 3, 1900.
2. *Phys. Rev.*, Vol. IX, No. 5, 1899.
3. *Phil. Trans.*, Series A, Vol. 199.

above ratio is known with much greater accuracy than we can measure the electromotive force of either in absolute measure.

Our absolute electrodynamometer has been rebuilt for permanency as follows: The stationary coil is wound in a single layer of 593 turns of No. 22 silk covered wire, on a plaster of Paris cylinder a little more than 47.3 cm. in diameter. The variation in diameter from one end to the other is only about one-tenth of a mm. The winding is about 41cm. long, or the length is to the mean radius of the axis of the wire as $\sqrt{3}$ to 1.

The suspended coil, consisting of No. 22 wire rolled flat, is wound in 40 turns on a ground porcelain cylinder 10cm. in diameter. This cylinder is suspended by a phosphor-bronze wire a meter long and approximately 0.7 mm. in diameter. The theory of the instrument and its construction were fully described by Patterson and Guthe in their paper on "A New Determination of the Electrochemical Equivalent of Silver[1]."

The preliminary measurements on the cadmium cell, which we hoped to make before this meeting, we have not been able to carry out. A series of cadmium cells, with amalgam containing 12.5 per cent. cadmium, have been made. No pains have been spared in the preparation of materials throughout The cells agree well among themselves, the variations being smaller than the limits of accuracy we are attempting.

The very low temperature-coefficient of the cadmium cell is an advantage of the greatest importance, and the uniformity shown by different series of cells is so marked as to constitute another count in its favor as a standard. No definite specification has ever been drawn up for the construction of this cell. I have therefore the following recommendations to make:

First.—That the INSTITUTE appoint a committee of three to prepare a complete specification for the normal cadmium or Weston cell.

Secondly.—That the cadmium cell, as thus specified, shall be adopted by the INSTITUTE as the standard of electromotive force, and that steps be taken to secure its legal adoption by Congress, provided it be dedicated to the public by the inventor, one of the distinguished Past-Presidents of this INSTITUTE.

1. *Phys. Rev.*, Vol. VII, No. 39, 1898.

Discussion.

President Scott:—It is almost superfluous to express the appreciation which we have for work of this kind and the excellent results which Doctor Carhart has presented to us. His name is a guarantee for what is the principal thing in this paper, which is its accuracy and reliability. Is there discussion upon this?

Mr. Sharp:—I wish to second very warmly Professor Carhart's recommendations. This matter of the legal standard of e.m.f. is a very important one. The difference which exists now between the standard e.m.f. in use in Germany and our own amounts nearly to one-tenth of 1 per cent. In other words, their volt is one-tenth of 1 per cent. different from ours. Now, in most engineering work that is not a matter of very great importance, but in any work of precision it is a matter of great importance, and it is extremely desirable to get rid of this intolerable difference.

The simplest and best way to do it would be to abandon the Clark cell as our primary standard of e.m.f. The Clark cell is a rather troublesome thing to use in work of precision. With it it is not so easy to attain an accuracy of even one-tenth of 1 per cent., on account of the uncertainty as to what the exact e.m.f. of the Clark cell is after it has undergone temperature changes. After abandoning our present standard we should, as Professor Carhart has suggested, go over to the cadmium cell, which is in every way better adapted for use as a primary standard of e.m.f. The cadmium cell is more easily prepared than the Clark cell and it is much more easy to use than the Clark cell.

The one necessary thing to this end is that sufficient representations be made to Mr. Weston to induce him to add to the great contributions which he has already made to the progress of electrical science, this one other contribution; namely, that he shall dedicate to the use of the public this cell. This dedication need not include the cell which is made and sold by the Weston Electrical Instrument Company, which is the under-saturated solution cell. The saturated-solution cell, which alone is adapted for use as a primary standard, is not, I believe, on the market in any form at the present day, and can be obtained practically only by making it one's self. If Mr. Weston were to consent to this, I believe we should signalize an event of considerable importance by going over, as the result of the deliberations of the forthcoming Congress, to the cadmium cell as a common and fixed basis for measurement.

Let me emphasize in this connection the importance of the standard cell to engineers in practical work. It will be conceded that no electrical laboratory, at least no college or technical school laboratory, is complete without an apparatus like the Wheatstone bridge. Nobody thinks of getting along without that. But you see a great many such laboratories that are utterly destitute of a potentiometer. Now, to my mind a potentiometer is an instrument of far greater engineering importance than the Wheatstone bridge, if we can compare things both of which are

so necessary. We need in engineering to measure two things; namely, e.m.f. and current. For measuring both of those according to the best methods we need a potentiometer in connection with a standard cell. The impression is, I think, rather widespread that standard cells are delicate things which must be handled with a great deal of care in order to get good results with them and not to destroy them. This impression is erroneous. The standard cell will submit to a good deal of bad usage and will recover from it. Short-circuiting a properly constructed cell will destroy its usefulness as a standard for a while, but after a comparatively short period, a day or two perhaps, it is back again where it ought to be and is uninjured. It is an extremely reliable thing to use. The potentiometer can be made in such a simple form that it can be applied in any engineering practice with very great facility, so that it is quite feasible to make it an adjunct practically of every central station, an instrument by which every central station man can keep his pressure exactly where it ought to be, can check his voltmeters and know what their errors are. Moreover, these checks can be made in positions where the ordinary electromagnetic direct-reading voltmeter is utterly at fault; that is, in the vicinity of heavy feeders and busbars carrying large currents, etc.

I think it is important, then, that the INSTITUTE take some action such as has been suggested in regard to the matter of a standard cell, and that it should aid in every way in the very important work which Prof. Carhart has in hand, of determining the value of the e.m.f. of the Weston cell.

MR. CARL HERING:—I thoroughly agree with the recommendation of Professor Carhart concerning such a committee, but would like to add that it would be well for that committee also to recommend specific and distinctive names for the two different cadmium or Weston cells, so as to avoid the confusion which now exists. At present it seems that the saturated cell is called the cadmium cell, and the unsaturated one is called the "Weston cell." It seems to me that the first one, being the real standard, should bear Weston's name. I would therefore recommend that the saturated cell be called the Weston cell, partly because its defeated rival for first place is also called by the name of its inventor; namely, Clark; and that the unsaturated cell be given some different name. The voltages of the two are slightly different, that of the unsaturated cell being the voltage of the saturated cell at 4° Centigrade, at which temperature it is saturated.

I also think it advisable to change the value which we have now adopted for the Clark cell, and make it conform more accurately to the theoretical definition of the volt. I am afraid there is a tendency to adopt as final, the present value of the Clark cell and to adhere to it, even though it may not agree with the absolute units. If we do not get a better agreement we will in time have to have such a thing as a mechanical equivalent of

electrical energy; at present this factor is a simple multiple of 10, but unless the value of the Clark cell is determined more accurately it is likely that some such incommensurate number will have to be used for accurate calculations.

PRESIDENT SCOTT:—Professor Carhart at the end of his paper has made certain recommendations. The committee which he has suggested will probably be one appointed by the Board of Directors of the INSTITUTE. If it is your pleasure a motion asking the Board of Directors to give it their consideration, may be made now.

PROFESSOR GOLDSBOROUGH:—In this country we are on the point of bringing into complete being a standardization laboratory under the auspices of the government at Washington. This Bureau is very hopeful of being drawn closely in touch with the electrical engineering profession and does not wish in any sense to have it considered as a physical laboratory, which is separate and apart from the electrical profession. I would like to make a motion which will incorporate the ideas which Professor Carhart has voiced, and, in addition, one other; namely, that a committee, such as that specified by Professor Carhart, be appointed by the Directors of the INSTITUTE, to report at the general meeting of the INSTITUTE which will be held in St. Louis in September, 1904, and that 25 copies of Professor Carhart's paper, together with the discussion on the same, be sent to the secretary of each of the National electrical engineers' societies abroad, and also to the secretary of each of the several standardization laboratories in Europe.

MR. HERING:—In seconding this motion, I would like to offer as an amendment, that this report be made as soon as possible, in order to give time for expressions of opinion both in this country and abroad, before the next Congress meets. It seems to me to be a mistake to *discuss* matters of this kind at the Congress. The real object of a congress is to *settle* a discussion. The discussion should precede the meeting of the Congress. I therefore beg leave to suggest the amendment that the committee report as soon as possible, say, early in the fall.

PROFESSOR GOLDSBOROUGH:—I would be very glad to incorporate that in the original motion, Mr. President.

(The motion was then put and carried.)

PROFESSOR CARHART:—Just a word or two more, please. I may say that our experience with this form of electrodynomometer is sufficient assurance to us that the new one will give us results on which we can depend. We are simply making an instrument the parts of which we shall know with greater certainty.

Secondly, I am very certain that the Bureau of Standards is heartily in sympathy with this whole matter. It may not be known to members of the INSTITUTE that Assistant Professor Guthe of my Department has recently been retained, I am very sorry to say, by the Bureau of Standards, to do exactly this work

there, and they are proposing to duplicate this instrument of ours as soon as they are able to (but of course we shall be far ahead of them, a good many months, perhaps a year or two), for the purpose of making similar measurements. I saw Professor Rosa, the physicist of the Department this week. So that I know they are entirely in sympathy with the whole movement; and, while I do not wish to dictate at all, merely to suggest, it would be very fitting if a member of the Bureau who is also a member of the INSTITUTE, were placed on this committee.

(On motion of Mr. Dunn, seconded by Mr. Hering, the report was adopted by a rising vote.]

PRESIDENT SCOTT:—The next paper is No. 8, " The Magnetic Units," by Doctor A. E. Kennelly.

Doctor Kennelly read the paper referred to, as follows:

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

MAGNETIC UNITS AND OTHER SUBJECTS THAT MIGHT OCCUPY ATTENTION AT THE NEXT INTERNATIONAL ELECTRICAL CONGRESS.

BY A. E. KENNELLY.

The committee appointed by the British Association for the Advancement of Science for the selection and nomenclature of dynamical and electrical units, published its first report in 1873.

That report recommended the adoption of the centimetre, gramme and second as the respective fundamental units of length, mass and time, on which the dynamic and electromagnetic systems of units should be based. The centimetre was selected in place of the metre, so as to make the density of water equal to unity.

The C. G. S. system of units thus promulgated, has become the recognized international scientific unitary system. It has met with almost universal satisfaction.

In constructing the C. G. S. basic units of electricity and magnetism, it is now easy to perceive that a bad selection was made. The unit magnetic pole was chosen as one which repelled its prototype at unit distance with unit force. A better selection would have been the pole which emitted unit magnetic flux, with a similar definition for the unit electric point-charge. The assumed system of electromagnetic units, thus amended, is sometimes spoken of as the "rational" system, in contradistinction to the existing system, which is then described as the "irrational system." The rational system would be more simple to express and to remember, for the reason that the numerical constant 4π or 12.566, which now appears in many fundamental electromagnetic equations, would have been eliminated

and introduced into spherical problems, where the constant naturally belongs. For example, the m.m.f. in a magnetic circuit would become equal to the current-turns linked therewith, instead of 4π times the current-turns. Consequently, many spherical electromagnetic problems that would naturally expect the 4π constant, now exclude it, and plane or rectangular problems, that would be simpler without it, now embrace it.

This criticism could scarcely have been foreseen at the time the C. G. S. electromagnetic system was constructed. It has taken years of acquaintance with the system to make the defect apparent.

If we could go back with our present knowledge, and create the C. G. S. electromagnetic system afresh, it would probably be better to adopt the "rational" system. To make the change now would require changing the magnitudes of the ohm, volt, ampere and other magnetic units by some power of 4π. The only exceptions would be the watt and the joule. They would escape.

It would be very troublesome to change all our electromagnetic measures. The trouble would be felt by every electrical industry. The change could only be made effective by international agreement. The only compensation for the trouble and expense would be a certain amount of scientific simplification in the theory of electromagnetism, and a certain benefit to scientific computers. The electrical industries would not receive any practical benefit, and any benefit they could receive would be that small indirect amount derivable from the simplification in theory already mentioned.

It seems too late, therefore, to attempt reconstructing electromagnetic units upon the C. G. S. system on a more rational basis. The majority would be inconvenienced for the benefit of the minority. It seems better that the student minority should make a little more effort to work with the existing "irrational" units, than to upset the existing order of electromagnetic measure in the hands of the many. In fact it is probably inadvisable for scientists to adopt the "rational" system in their writings, since the labor of reading electrotechnical papers is often greatly enhanced by the uncertainty as to which of the two systems is being employed.

The case is reversed as regards the rational use of the metric system of weights and measures. In this country, and in Great Britain, the system of customary weights and measures is a burdensome incoherent medley with absurd inconsistencies and

ambiguities. The metric system is far simpler and better, besides being in otherwise international use. The change from the customary to the metric system would entail much trouble and some expense, but it would effect a great reduction of aggregate national labor in learning, employing, exchanging and computing. The change would be nationally economical, so far as can be judged from the internal evidence presented, as well as from the evidence of the various countries that have already made a similar change.

Several ingenious expedients have been proposed for effecting partial "rationalisation" of the C. G. S. electric and magnetic units, without changing the values of the concrete practical units. All thus far proposed introduce a new factor into fundamental or defining equations in order to get rid of the 4π constant in other equations, so that the 4π difficulty is thereby not eradicated but merely transported. It is very doubtful whether such half-hearted expedients can succeed. It seems better to let the existing system alone.

In adapting the C. G. S. system of magnetic units to practical requirements, the inconvenient magnitudes of many C. G. S. units became apparent. The C. G. S. unit of e.m.f. was ridiculously small, since an ordinary Daniell cell showed 110 millions of them. A similar condition was found for the C. G. S. unit of resistance; since a Siemens unit, in extended use at that time, containing about a trillion C. G. S. units. In order, therefore, to aid practicians, the working unit of e.m.f. was selected as 10^8 C. G. S. units of e.m.f. under the name of the volt; while the working unit of resistance was selected as 10^9 C. G. S. units of resistance, under the title of the "ohm." These practical magnitudes having once been adopted, a practical system of units inevitably came into existance, one volt through one ohm producing one ampere; one ampere carried for one second delivering one coulomb, and so on. The practical units differed from their parents, the corresponding C. G. S. units, by differing multiples or powers of 10. In one instance, the ratio between a C. G. S. unit and its practical representative is 10, in another it is 10^9, in another 10^7, and so on. Moreover, the practical system of the ohm, volt, ampere, coulomb, joule, watt and henry, is such as would have been arrived at directly, if the unit of length had been an earth-quadrant, or 10^9 centimetres, instead of one centimetre, and the unit of mass 10^{-11} gramme, instead of the gramme, the unit of time being the second in both systems

Thus there has been created the fundamental centimetre gramme-second system in which the theory of electromagnetics is learned, and to which all science is referred. Side by side with the C. G. S. system is the practical, or quadrant-eleventh et gramme-second system, or Q. E. S. system, in which most of the units have been christened for industrial use. The C. G. S. system is thus the language of the esoteric; while the Q. E. S. system is the electrical vernacular.

The divorce of the practical from the scientific system was a grave mistake, although it was probably hard to foresee. After years of experience it is now easy to see that the correct original course would have been to christen the C. G. S. magnetic units, without regard to their particular magnitudes, and, at the same time, to adopt a suitable series of prefixes for decimal multiples and submultiples, in extension of the existing micro-milli-kilo-mega system. If, for example, the C. G. S. magnetic unit of current-strength (10 amperes), had been originally christened the ampere, our present ampere would have been known as the deci-ampere, and in a few days we should have become as familiar with such a deci-ampere as we are with the existing ampere. This is shown by the case of the *microfarad*, which is as simple and convenient a term as if this standard capacity had been originally called the farad. We should then have retained the C. G. S. system for both the esoteric and the vernacular, but would have adopted for practical work certain multiples with their appropriate prefixes.

It is probably now too late to retrace our steps. We cannot annul the Q. E. S. system and exclusively adopt the C. G. S. system for practical work. Nor is it worth while upheaving decimal relationships. Thus, it has been suggested that the existing dekavolt might be changed in name to the volt, by increasing the volt to ten times its present magnitude, in order to make the new ampere agree with the C. G. S. unit of current. This would entail a slight advantage over the existing practical system. It would, however, effect a confusing hiatus in technical literature and would still leave a practical system divorced from the C. G. S. system with numerical ratios of 10^9 and 10^{-9}. The Q. E. S. system is in satisfactory industrial use all over the world, so far as it goes; viz., through the eight units: volt, ampere, ohm, farad, coulomb, henry, joule and watt. But we can with advantage stop further unnecessary divergence, by refraining from christening any more units in the Q. E. S. system, and by bestowing all future names

on the C. G. S. system. A start in this direction has already been made. The international electrical Congress in Paris at 1900 christened the C. G. S. magnetic units of flux and flux-density, under the names of maxwell and gauss respectively. These terms have already come into fairly extended use in America and into somewhat more limited use in Europe.

It is very desirable that the next international electrical congress should complete the units of the magnetic circuit by bestowing names upon the C. G. S. units of m.m.f. and of reluctance. The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has for several years provisionally recommended the names "gilbert" and "oersted" for these two units. They are already in some use in America. If they should be adopted, we would have the relations:

$$\frac{\text{gilberts}}{\text{oersteds}} = \text{maxwells}$$

$$\frac{\text{maxwells}}{\text{sq. cms.}} = \text{gausses}$$

The ampere-turn is a very convenient unit of m.m.f. close to the C. G. S. unit in order of magnitude; but a name for the C. G. S. unit is very desirable.

By rights, every C. G. S. electromagnetic unit should have a name. There is not even a recognized weed, or germ, that does not have a name. Practically all the fifteen hundred millions of people inhabiting the world have names. It would seem that a fundamental C. G. S. electric or magnetic unit is of as much importance as a weed or a bacillus. Moreover, it is fortunately unnecessary to learn the names for units, or commit them to memory, if the units are rarely used. It would be sufficient to have authorized names accessible and definite, ready for use when required.

Moreover, our minds are so constituted that until we possess a name for a thing, the thing remains more or less symbolical, and is not fully realized as concrete. Thereby the C. G. S. system of electromagnetic units, which is necessary and fundamental becomes hampered and retarded. It is desirable for scientific purposes, for educational purposes, and in the interests of progress, that these international C. G. S. units should have recognized names.

For example, the fundamental rule for the electromotive force of a direct-current bipolar dynamo is

$$e = \varphi n w. \quad \text{C. G. S. magnetic units of e.m.f.}$$

where φ is the useful flux from pole to armature in maxwells, n the speed of rotation in revolutions per second and w the number of wires on the surface of the armature. If we divide e in this equation by 10^8, we get the result in volts; but the *C. G. S. magnetic unit of electromotive force* is worthy of a name, if only to avoid the objectionable periphrasis.

The expedient suggests itself of attaching the prefix *ab* or *abs* to a practical or Q. E. S. unit, in order to express the absolute or corresponding C. G. S. magnetic unit. The advantages of the plan are that it is almost self-explanatory, and requires no effort of memory to acquire; also that it is self-suggesting in all the important European languages. According to this plan the

C. G. S. magnetic unit	of	e.m.f.		would	be	the abvolt
"	"	"	resistance	"	"	absohm
"	"	"	current	"	"	absampere
"	"	"	quantity	"	"	abcoulomb
"	"	"	capacity	"	"	abfarad
"	"	"	inductance	"	"	abhenry or centimetre
"	"	"	energy	"	"	abjoule or erg
"	"	"	power	"	"	abwatt

We would also have the following ratios:

1 abvolt	= 0.01 microvolt	$= 10^{-8}$ volt	
1 absohm	= 1 bicrohm	$= 10^{-9}$ ohm	
1 absampere	= 1 dekampere	= 10 amperes	
1 abcoulomb	= 1 dekacoulomb	= 10 coulombs	
1 abfarad	= 1 begafarad	$= 10^{9}$ farads	
1 abhenry	= 1 bicrohenry	$= 10^{-9}$ henry	= 1 cm.
1 abjoule	= 0.1 microjoule	$= 10^{-7}$ joule	= 1 erg
1 abwatt	= 0.1 microwatt	$= 10^{-7}$ watt	

On such a basis the preceding equation would be written

$$e = \varphi n w \text{ abvolts},$$

with great advantage in clearness and comprehensibility.

In a comprehensive system of electromagnetic terminology, the electric C. G. S. units should also be christened. They are sometimes referred to in electrical papers, but always in an apologetic, symbolical fashion, owing to the absence of names to cover their nakedness. They might be denoted by the prefix *abstat*. Thus, the

C. G. S. electric unit of	e.m.f.	would be the	abstatvolt
" " "	resistance	" "	abstatohm
" " "	current	" "	abstatampere
" " "	quantity	" "	abstatcoulomb
" " "	capacity	" "	abstatfarad
" " "	inductance	" "	abstathenry

The abstatjoule and abstatwatt are the same as the abjoule and abwatt respectively. These units would also be almost self-explanatory in any European language and would call for no appreciable effort of memory.

We should then have the following ratios ($v = 3\times10^{10}$ approximately):

1 abstatvolt	$= v$ abvolts	$= 300$ volts
1 abstatohm	$= v^2$ absohms	$= 9\times10^{11}$ ohms
1 abstatampere	$= v^{-1}$ absampere	$= 3.3\times10^{-10}$ ampere
1 abstatcoulomb	$= v^{-1}$ abcoulomb	$= 3.3\times10^{-10}$ coulomb
1 abstatfarad	$= v^2$ abfarad	$= 1.1\times10^{12}$ farad
1 abstathenry	$= v^2$ abhenrys	$= 9\times10^{11}$ henrys*

It is desirable that some such system of christening the C. G. S. magnetic and static units, without burdening the memory, should be adopted by an international electrical congress.

It seems also desirable that an international electrical congress should sanction the use of the Hefner Alteneck Reichsanstalt standard amyl-acetate lamp as a secondary standard of light or luminous intensity. The lamp is in extended use for determining the intensity of incandescent lamps, and as such should receive recognition.

It is also desirable that steps should be taken by an international electrical congress to establish a uniform international basis for the standardization of electrodynamic machinery. The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has already formulated, through the work of a committee, a series of standardization rules, relating to nearly all classes of dynamo-electric machinery. A similar series of rules differing from the last named in various details has been promulgated in Germany by the Verband der Deutcher Electrotecknikер. Still other rules are extant locally in other countries. It is perhaps possible to carry the principal of international standardization too far into detail, since many details depend in each country upon local,

*The abstat henrys regarded as a length, according to the conventional system of dimensions contains 9×10^{11} earth quadrants, a distance that light would take nearly one thousand years to cross.

commercial and industrial conditions; but, on the other hand, there are many underlying physical and electrotechnical conventions that might receive international consent among electrical engineers. For example, a dynamo machine ought to have the same rating, based on temperature-elevation under load, all over the world, and the rules by which the rating of a dynamo is experimentally determinable might well be adopted by an international electrical congress, together with many similar matters, under this general title of standardization. Such a consensus of opinion would probably take time to evolve and an international electrical congress might appoint a standing committee to confer upon the question of standardization with instructions to report at a future time. Much scientific and engineering benefit might be hoped for from the efforts of such a standing committee on international standardization.

DISCUSSION.

MR. HERING:—I did not understand whether the prefix "ab" for the C.G.S. units was to apply to the electromagnetic units or to the electrostatic, or to both. If it applied to both there would be confusion. I presume it is intended to be applied only to the electromagnetic units.

Doctor Kennelly said that the last Congress at Paris in 1900 *created* some units. That is not quite right; it did not *create* them, it simply *named* some existing absolute units.

PROFESSOR GOLDSBOROUGH:—Before we pass on to the next paper, may I be permitted to say a word or two in reference to Doctor Kennelly's paper? For a number of years past I have found it very convenient indeed to make up a few names for the magnetic units which thus far have not been christened, and use them commonly in discussing matters pertaining to electromagnetism with our students. I have found that as soon as we can give to the student a definite name for a specific thing, he gets a concrete idea of what it is very much more readily.

We are nearing the time when we shall undoubtedly use the metric system in all engineering work. The Mechanical Engineers are taking the matter up for serious consideration, and consideration has been given the matter by the INSTITUTE. It is only a question of time when the English measures will pass out and the metric system will come in. Why should we not, then, prepare for this by having the magnetic units properly named so that ultimately when we begin to speak, say, of magnetic reluctance per centimeter, we shall have specific unit of measure of this quantity. To my mind it is highly important the new generation of engineers that is coming should get correct conceptions of what all the units stand for.

I should like, Mr. President, to offer another motion, to the effect that copies of Doctor Kennelly's paper when printed be sent, with copies of Doctor Carhart's paper, to the secretaries of the various institutions mentioned, for distribution and for the purpose of calling attention to matters that have been under discussion here this morning.

PROFESSOR J. P. JACKSON:—Mr. President, in seconding that motion, I wish to suggest that Doctor Kennelly was exceedingly delicate with reference to existing standards, and rightly so; and on the other hand, he wished to get as nearly as possible to our fundamental system. I feel that in his paper he can afford to use a good deal of positiveness in reference to a method of arranging new units whereby our literature, which is growing rapidly and assuming permanent shape, will not have any constants whatsoever, at least so far as standard formulas are concerned.

I second Professor Goldsborough's motion.

(Carried.)

MR. HERING:—Doctor Kennelly gave the impression that the Hefner unit of light was the one generally used in this country. Some time ago I was anxious to know whether this was or was

not the case, and therefore made inquiries which showed that the prominent gas lighting and electrical lamp companies use the British candle, which is a larger unit than the Hefner. Measurements are often made in terms of the Hefner unit, and are then reduced to the uncertain British candle.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

THE CATHODE RAY ALTERNATING CURRENT WAVE INDICATOR.

BY HARRIS J. RYAN.

During the past three years I have had considerable experience in the use of the Braun type of cathode ray tube to determine the character of rapidly changing electric currents. In this experience I developed the following method for using this form of tube as an alternating current wave indicator. By means of the method this instrument fills much the same sort of a want in the detail study of many alternating current phenomena as does the indicator in the study of the cyclic performance of steam in the steam engine.

I have found the method so convenient and satisfactory in a large class of work compared with other and more usual methods that I am confident that many members of the INSTITUTE will find its employment often convenient and most useful in their own work.

DESCRIPTION OF THE METHOD.

The usual form of cathode-ray tube employed for indicating alternating currents is shown in Fig. 1. The cathode and annode are connected to the negative and positive conductors respectively of a motor-driven Wimshurst electrostatic machine. A current of about .0005 ampere is set up in so doing and the cathode rays are driven forward through the tube, striking the glass diaphragm which is opaque to them. All of the rays are stopped at this diaphragm except those which pass through a small aperture at its center. This pencil of rays continues until they strike the screen where they cause a brilliant spot of fluorescent light. The screen is of mica spread with white powder that powerfully fluoresces when struck by the cathode ray.

Comparatively weak magnetic fields will cause large deflections to the ray. Thus if a continuous current be passed through the coils, c′ c′, mounted just beyond the diaphragm as shown in Fig. 1, of sufficient strength in regard to the number of turns in the coils so as to produce a m.m.f. of about 50 ampere-turns, the ray will be deflected well to one side of the center of the tube, causing a corresponding displacement of the spot of light on the screen to the point marked +. Such deflection is due to the magnetic field set up across the cathode ray by the current in the coils. When the current ceases the spot of light produced by the ray returns to its normal position at 0. If the current is set up in an opposite direction, the spot of light will shift on the screen to the point marked −. When an alternating current having the same maximum value is substituted for the continuous current, the spot of light will vibrate between the + and − positions, and owing to the persistence of vision will appear as a band of light.

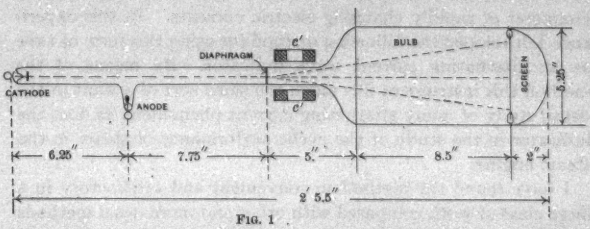

FIG. 1

By looking at the screen as seen reflected from a revolving mirror, the spot of light actuated by an alternating current will trace a wave that will have the same form as the wave of current which is passed through the coils due to the fact that the cathode ray has no appreciable inertia. Some investigators have revolved the mirror synchronously and thus obtained a stationary wave which is most satisfactory to look at and which may be readily photographed. The synchronous driving and satisfactory adjustment of the revolving mirror involve expensive apparatus that is cumbersome and tedious in manipulation, to avoid the use of this apparatus I have devised the following method:

Reference is here made to Figs. 2 and 3. Two sets of coils are applied just beyond the diaphragm and mounted with their axes at right angles and in the same plane as shown in Fig. 2. The coils having the axis *ab* set up a horizontal field and which when established with alternating currents will produce the

vertical motion of the spot of light producing a luminous band on the screen shown at *ab* in Fig. 3. Similarly, the coils having the axis *cd* produce the horizontal motion of the spot and the band *cd*. When the alternating currents are set up simultaneously through both sets of coil, the spot of light will be subject to both motions tracing the card shown in the figure.

In order that definite results may be obtained, only one of the wave forms of the two currents may be unknown; the other must be of known form. The most suitable known form is that of a true sine wave. To secure a true sine wave of current with ample accuracy for all practical purposes, I have employed the following arrangement of inductance and capacity. Referring to Fig. 4, AC are leads from an alternating source of unknown pressure wave-form supplying the current to an apparatus at M

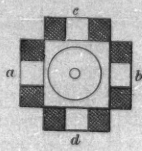

FIG. 2

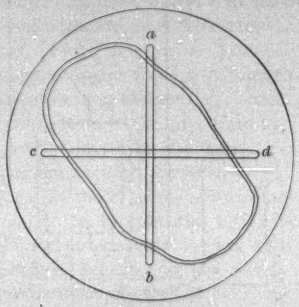

FIG. 3

that is to be observed. The circuit through M leads through one set of coils mounted at $c_1 c_1$, so as to give a motion of the cathode ray that is proportional to the instantaneous values of the current through M. The current that produces the standard sine wave motion of the cathode ray passes through the coils $c_2 c_2$ with their axes at right angles and in the same plane of the axis of the coils $c_1 c_1$. This current is obtained from the source having an unknown pressure wave form at $a' c'$. It passes from c' through the single path L' and the paths C and L'' in multiple, and finally to the source at a'. The coils $c_2 c_2$ are connected in the branch L''. L' and L'' are inductive reactances made by mounting coils on straight laminated iron cores. The ohmic resistances are made as low as is ordinarily convenient and possible compared with the corresponding values of the reactances. C is an ordinary paper

condenser. The reactances of C and L'' are adjusted so as to be approximately equal and, therefore, so that resonance is established to some extent due to the exciting current that is set up through L'. All who have made a study of the characteristic properties or behaviors of the harmonic elements or component irregularities in relation to inductance and capacity will note at a glance the powerful action that this circuit will exert in expurgating the current that passes the branch $L''\ A\ c_2\ c_2$ of all irregularities causing it to have a simple sine wave form.

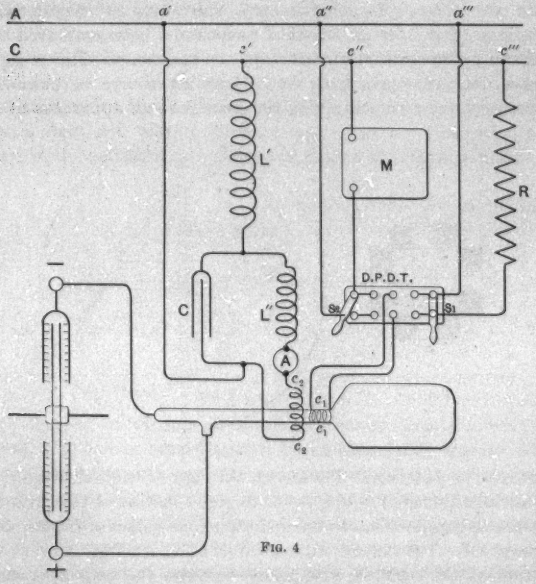

FIG. 4

I have usually adjusted this circuit so that a current of .2 ampere passed L', and 1 ampere circulated through the resonant circuit $C\ L''\ A\ c_2\ c_2$. Thus arranged the third harmonic will be reduced to *one-third* compared with the *fundamental* in passing L'; a further reduction of *one-third* of the third harmonic occurs through L'' which acts as a throttle for all harmonics while the condenser passes the third harmonics with a facility measured at *three times as easy* as for the fundamental. A further reduction factor of 5 to 1 acting alike against the third as well as all higher

harmonics is applied by the current multiplying process due to resonance. All current circulated through $C\,L''\,A\,c_2\,c_2$ due to resonance must have the simple sine form so long as the saturation m.m.f.'s utilized by the iron cores are small compared with those used by the air cores in the magnetic circuit of L''. Thus it is seen that there are approximately the following factors which combine to cut out the third harmonic.

$$3\times3\times3\times5 = 135$$

which means that in the above circuit the value of the third harmonic compared with the fundamental circulating through $c_2\,c_2$ has been reduced to *one hundred and thirty-fifth* of the original value existing in the e.m.f. wave impressed by the source upon this circuit at $a'\,c'$. Since even in very bad cases of wave distortion in e.m.f. generation the third harmonic will not exceed one-third of the magnitude, it follows that the ratio of the fundamental and third harmonic values of the current through $c_2\,c_2$ is about *four hundred*. Since the higher harmonics are eliminated to a greater extent than the third it follows that the deviation of the current wave through the coils, $c_2\,c_2$, that are to produce the standard known motion of the ray, from the cyclic variation of a true sine wave is less than *one-quarter per cent.*, an accuracy that is ample for the purposes involved.

By means of the analytical methods published by Steinmetz, the exact degree of expurgation of irregularities in the wave of the original source is easily computed where " open " magnetic circuits employing straight cores operated at low flux densities are used in making up the inductances L' and L''.

The degree to which the above expurgation of irregularities will occur in actual operation has been examined carefully in a number of ways and found to be about as described above.

When the unknown current through M and the coils at $c_1\,c_1$ and the sine wave current through the coils at $c_2\,c_2$ are established at the same time, the spot of light on the screen in the cathode ray tube is given a motion that is the resultant of two motions at right angles to each other and proportional to the instantaneous values of their corresponding currents. Owing to the persistence of vision, this results in the production of a closed card upon the screen traced by the spot of light. A record of this card may be made in various ways. I have generally used one of the two following methods:

1. The card may be easily photographed in the ordinary camera using five seconds exposure.

2. It may be traced on a smoked glass mounted in front of the tube by keeping the eye at a fixed point of view.

I have generally preferred to record the cards by photographing them.

Ordinarily the detail of the pressure wave with respect to the current wave that it established is also desired. By means of switches S_1 S_2 and D P D T in Fig. 4, the coils at c_1 c_1 can be disconnected from the circuit a'' M c'' and connected in the circuit which draws current through a non-inductive resistance a''' R c'''. This produces a card due to the pressure wave-form impressed upon the machine or apparatus at M. Obviously, when the currents through M and R differ widely in magnitude, an extra set of coils may be mounted concentric with the coils c_1 c_1 through which to receive the current controlled by the non-inductive resistance R. Both cards may be photographed on the same plate when a true record is obtained of instantaneous

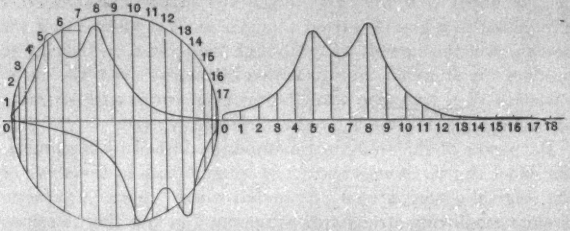

FIG. 5. E.M.F. WAVE OF OLD T-TOOTHED ARMATURE ALTERNATOR.

values and phase relations of the unknown e.m.f. and current applied at M. To enable the values to be plotted in rectangular coördinates, the axis of the standard or sine wave should also be recorded. This is easily done by removing the current from the coils c_1 c_1 and recording the line of light produced by the sine motion that remains due to the standard current in the coils c_2 c_2.

If a polyphase source is employed it is best to apply the sine wave current through the coils, c_2 c_2, from a pressure phase changing device. This is easily and obviously arranged by means of a set of autos having a number of pressure taps or by means of a movable coil mounted in a revolving field such as is provided by every induction motor that has a wound secondary. Thus the phase position of the sine wave can be adjusted so as to cause the more intricate portions of the unknown wave form to occur at the time when the sine wave motion is most rapid,

i. e., when the sine wave current is passing through zero. In this manner the resulting cards can be so adjusted as to bring out the desired detail to the fullest and clearest extent.

In a simple and obvious manner the values of the unknown wave may be taken from its card and plotted with time in rectangular coördinates. One way of doing this is illustrated in Fig. 5. A circle is drawn using the sine wave as a diameter. Upon this circle a number of equidistant points are located corresponding to the number of points to be used in plotting the wave in rect-

FIG. 6.

angular coördinates. Ordinates to the sine wave diameter of this circle will intercept the card at uniform time intervals. The lengths of the ordinates from the card to the diameter are proportional to corresponding instantaneous values of the wave and may be transferred without change to the rectangular diagram to form the actual wave as shown in Fig. 5.

The scale that applies to the instantneous values is determined by comparing the effective value of the observed wave with the

reading of an alternating current ammeter placed in series with the sine wave coils, $c_2\ c_2$. This ammeter is read at the time that the card formed by the unknown wave is recorded. The ratio between the deflections of the ray produced by the coils $c_1\ c_1$ and $c_2\ c_2$ is easily obtained once for all by means of observations taken with continuous currents and instruments.

The half tone in Fig. 6 was made from a photograph of a set of cards and their axes as they were formed on the screen of the cathode ray tube. In making these cards the method was being employed in a study of the conductivity of the atmosphere about a line conductor subjected to high pressure. The card $L\ C$ was formed by the line-charging current and the card $C\ C$ by the charging current supplied to an air condenser for the purpose of determining the e.m.f. wave impressed upon the line. The coils corresponding to $c_1\ c_1$ in Fig. 4 in this instance con-

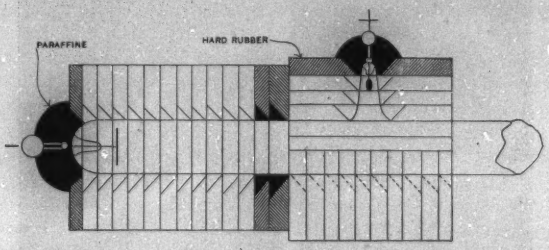

FIG. 7

tained a total of 46000 turns which would enable cards to be formed with currents of from .0006 to .006 ampere, *i.e.*, from .6 to 6 milliamperes. The effective e.m.f. employed was 40,000 volts at 120 cycles.

In order to use this cathode ray instrument on high pressure circuits some natural precautions must be taken. The tube, coils, Wimshurst machine and camera must be completely enclosed in a wire cage set upon high pressure insulators and connected to one terminal of the high pressure source. The branch $L''\ A\ c_2\ c_2$ delivering the standard sine wave from the low pressure source must be protected by inserting an insulating transformer so as to separate with an ample dielectric the coils $c_2\ c_2$ and the remainder of the low pressure circuit $L''\ A\ a_1'$. Such an insulating transformer is easily provided by mounting primary and secondary annular coils having a transformative ratio of 1:1 upon a straight open-circuit core and separated therefrom by a suitable

space to be occupied by the dielectric and then by immersing the whole transformer in ordinary kerosene. Obviously all metallic circuits within the high pressure cage should be grounded to it. In this manner I have found that many of the interesting atmospheric conduction phenomena that occur in high pressure work may be studied experimentally in a satisfactory manner.

I think that this apparatus will in the future be found of use in observing the behavior of hunting currents in synchronous machinery, commutation in continuous current machinery, the characteristic manner of current interruption produced by fuse cut-outs, and circuit breakers and electric surges on long lines.

As was shown above, it is easily applied where cyclic phenomena are to be observed. It can, however, frequently be used effectively for observing values that occur only as sudden impulses, by having the current constituting the sudden impulse through one circuit and a uniformly increasing current through another circuit occur simultaneouly and arranged so as to act magnetically upon the cathode ray. A momentary trace showing the nature of the impulse is thus drawn across the fluorescent screen.

When I determined to examine into the fitness of the Braun type of cathode ray tube for engineering research work I found that the tubes on the market were altogether too small to be of practical use. In the summer of 1900 Mr. Muller-Uhri of Braunschweig, Germany, undertook to make for us two tubes in which the screens would be as near to 6 inches in diameter as he could make them. The glass work is difficult and only after a number of trials did he succeed in making two in which screens were 5 inches in diameter. These landed in my laboratory in safety. A drawing to scale of one of these tubes is given in Fig. 1.

At the outset I was greatly disappointed in the behavior of this large size of tube compared with that noted in the small tubes. The cathode ray produced by the discharge from the influence machine was intermittent and almost wholly unsatisfactory. During the next two years I spent such available time as I could spare in a study of the causes of this intermittent character of the ray. The trouble was finally traced to conductivity of the atmosphere that occurs at the rather high pressure that must be applied between the cathode and annode of the tube. The pressure required will spark a distance of $\frac{3}{4}$ inch between 3 inch balls. As soon as the real cause of the trouble was understood the remedy was easily found and applied.

To cause the formation of a continuous steady ray, therefore, it is necessary to jacket the tube at the cathode and annode portion with an ample solid dielectric. Oil for this purpose is a complete failure because it is too mobile. The best manner as yet that I have found for applying the jacket, so as to keep the air away from the immediate exterior of the electrodes, is shown in Fig. 7. The jacket is built up from quarter-inch hard rubber discs and half discs cemented to the walls of the tube with paraffin in the manner illustrated.

Such a jacket completely overcomes the unsteadiness of the ray, enabling one to operate the tube from an ordinary Wimshurst machine by connecting its cathode and annode direct to the terminals. All metal parts and connections from the Wimshurst to the tube should nowhere have a radius of less than $\frac{1}{8}$ inch, *i.e.*; the conductor should be at least $\frac{1}{4}$ inch in diameter.

I have found that a Wimshurst using six pairs of 17-inch micanite plates, driven at 200 r.p.m., would furnish about all the current that may be passed through the tube without puncturing. This gives a most brilliant spot of fluorescent light upon the screen. While attempting to drive more current through one of the tubes it was punctured when operating the Wimshurst at a speed of about 250 r.p.m. This tube will operate satisfactorily with the discharge from a Wimshurst having a single set of 18 inch plates. The amount of light at the spot seems to be proportional to the current-discharge through the tube, and therefore, to the number and size of the plates used in the construction of the Wimshurst.

Mr. Muller-Uhri is now prepared to supply these extra large tubes to the trade at an export price of about $20 at Braunschweig, Germany. The rubber jackets described above must be mounted after the tubes have been received from the makers. Doubtless in the near future some method will be found that will enable the maker to mount upon the tubes a proper and sufficient jacket before sending them out.

I wish to acknowledge the efficient and extensive assistance rendered by Professor J. O. Phelon in the early work done upon these large tubes, whereby I was ultimately able to trace the real cause of the intermittent character of the cathode ray.

Discussion.

Mr. Dunn:—I wish to express my appreciation of the wave-form tracer that Professor Ryan has just described, although I know that some of my friends here will say, "What has a direct-current man to do with wave-forms?" While it is a little off the line of the discussion perhaps it would be interesting to see why this form of wave-tracer is so valuable in direct current.

The ordinary frequencies of alternating currents are, say, from 25 to 60 cycles per second; the frequencies of lightning, hundreds of thousands per second. The direct-current man's frequencies are in the region between these and vary from about 800 to 8,000 per second. The latter frequencies occur in the complicated phenomena of commutation.

Many of these phenomena have yielded to experimental and other analyses but others have seemed beyond this with the methods available, but a curve-tracer such as Professor Ryan brings out will, I believe, be of the greatest assistance in the study of the complicated, irregular, high-frequency waves with which a direct-current armature is teeming. The inductive interferences in direct-current armatures have been greatly reduced by the study of these waves in the last few years; it is to be hoped that they may be still further reduced if we have a wave-form indicator like Professor Ryan's capable of dealing with the frequencies involved.

Mr. Thomas:—I would like to ask Professor Ryan how he best takes the records of these wave-forms, how much light he gets for photographic work, how long it takes, and also whether it is possible to get a changing phenomenon; that is to say, a discharging condenser where there are no two waves alike.

Professor Ryan:—It is not possible, Mr. Thomas, to photograph single tracings? The light that is given off by either the luminosity of the cathode or the fluorescent screen is not strong enough for that after being transmitted through the mica screen and the glass of the tube. However, for periodic work it is easy to photograph, as photographic apparatus is usually made up with regard to sensitiveness of the plates and all that, with an exposure of from two to five seconds, depending on the strength of the current that we are running through the cathode ray tube, for the invokement of the ray; and for all ordinary inspectional work a very convenient method is simply to have a fixed point of view for the eye and a lightly smoked glass in front, and you can trace the card with any convenient tracing point.

Professor A. F. Ganz:—I should like to ask Professor Ryan whether all the records come out in the form of such broad bands as are shown in Fig. 6, page 1423, and if they do I should like to ask how he passes from these broad bands to the well-defined lines shown in Fig. 5.

Professor Ryan:—That in Fig. 5 was a tracing on smoked glass taken by looking at the center of the line. It should be remembered that Fig. 6. in order to reproduce well, had to be

taken at an exposure of 10 seconds, and that was on a 130 cycle circuit, and the cathode ray tracer went around there 1300 times. You can see that although the line is somewhat broadened it repeated itself fairly well; and it is somewhat remarkable that retracing 1300 times did not give a broader record than we have there. In running during a two or three seconds exposure, instead of ten, the line would be narrower than that under ordinary conditions. The lantern-slide here exhibited was made at a time when we didn't have complete facilities, had only a small Holz machine for exciting the ray, and that was very weak, and the exposure three had to be made for five minutes instead of two or three seconds.

MR. WILLIAM J. HAMMER:—I would like to ask Professor Ryan whether he has ever used the Lenard tube with an aluminum window so as to bring the cathode ray outside, which will perhaps enable him to get rid of any possible error due to the mica and the glass, and enable him to make a record directly on photographic paper by means of a moving picture film. Single images could be readily obtained by regulating the speed of the film. I have been doing some little work with a Lenard tube recently, and it occurred to me that perhaps that could possibly be used in this apparatus, and I would like to know whether Professor Ryan has tried it or whether he considers that it would be practicable.

PROFESSOR RYAN:—I have not done so. That is a very interesting suggestion indeed. I do not know how one would succeed.

DR. SHARP:—I think the facts concerning the Lenard arrangement are these, that the cathode rays which are obtained through the window are very quickly absorbed by the atmosphere; that they do not go any considerable distance outside.

MR. HAMMER:—Mr. Tesla told me recently of some experiments he had made in which he used a very powerful apparatus, and he spoke of drawing the rays outside of the Lenard tube, and in a 30 seconds exposure losing all the nails on one hand, and he spoke of being able to carry the stream a considerable distance, even stating that with a specially designed tube for very high voltages he could kill a man a mile off. So it would depend largely on the character of the apparatus which produced the cathode stream; I have myself succeeded in bringing it out a farther distance than you have referred to.

MR. FISHER:—I am very much interested in this apparatus and would like to ask Professor Ryan whether this apparatus can be produced complete so that the manufacturer can take it and use it immediately. The manufacturer does not want to adjust his self-induction and capacity to get an exact sine wave.

PROFESSOR RYAN:—In reply to that, the apparatus as shown in the diagram on page 4 for the securance of a sine wave known motion of the ray is that which you have in any testing laboratory and is so easily set up that I scarcely think any one would care

very much to buy an especially produced outfit, because that same apparatus at other times might be used for other purposes. It is easily put together and the sine wave invoked. It has always occurred to me in that way. I use the same apparatus on another day for other things.

PROFESSOR LANGSDORF:—It is interesting to note in Fig. 4, on page 1420, that the means for obtaining the sine wave consists of two choke-coils in series and a condenser connected across from the middle point of these two to the other side of the line. If the two choke-coils have equal inductances, and if the capacity reactance of the condenser is numerically equal to that inductance, we have the constant potential constant current transformer system.

About two years ago, at Professor Ryan's suggestion, I made some calculations to determine whether there was any special relation between the values of L', L'' and C, which would produce a maximum damping out of the harmonics. This was done by the use of the complex imaginary quantity; it developed that there was no special condition of maximum damping, but that by changing the relations between these quantities a definite amount of damping could be obtained.

PROFESSOR GOLDSBOROUGH:—I feel very strongly that the INSTITUTE owes Professor Ryan a very hearty vote of thanks for the paper which he has given us to-day. Professor Ryan has given us an instrument which is, I believe, far superior to any other curve tracing instrument that has thus far been brought forward. It is free from a great many of the drawbacks of other instruments and it has few parts that will get out of order. There are no commutating contacts, and no clock-work mechanisms or other special means required for determining the rate of travel mechanically of parts of the apparatus. I am quite sure that in connection with the long distance transmission of power, as well as in the field of telephony, there are a wonderfully large number of problems which it has been absolutely impossible for us to study properly for the want of just such an instrument as Professor Ryan has given us; and for him to have brought this down to an instrument which can be used commercially, not a physical laboratory instrument at all, is to my mind a wonderful achievement on his part. We probably know very little of the energy and time and life that Professor Ryan has put into the development of this instrument, and I am very much inclined to believe that the reason we have not heard more from Professor Ryan in the last few years than we have, is because he has been building up and preparing something for us that is extremely good. It gives me, therefore, great pleasure to offer this resolution.

Resolved, That a vote of thanks of the INSTITUTE be tendered to Professor Ryan for the magnificent wave-tracing instrument which he has devised and which he now presents to the electrical fraternity.

DR. KENNELLY:—I second the motion, Mr. President.

PRESIDENT SCOTT:—You have heard the motion, that we express the appreciation of the INSTITUTE for what Professor Ryan has already done. I think, however, we need not regard this paper as completing the subject, as it gives great promise for the future by presenting a new instrument for research.

(The motion was carried.)

PRESIDENT SCOTT:—Professor Ryan, you have our sincere thanks and appreciation.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

SOME NOTES ON CERTAIN UNDERGROUND HOISTING PROBLEMS ON THE WITWATERSRAND.

BY A. W. K. PEIRCE.

Gold mining on the Witwatersrand consists chiefly of the exploitation of the "Main Reef Series," a bed of gold-bearing conglomerate with an east and west strike, and dipping to the south at a fairly uniform angle in the neighborhood of 30°. For an extent along the strike of some 50 miles this reef series has been proved to be gold-bearing, and the continuity of the deposit has been proved by actual mining and by bore holes to such a depth on the dip that mining ground is held at a high valuation even where the ultimate mining depth cannot be less than 8,000 feet (vertical) or even more*.

The permanence and the uniformity of average dimensions and values of these gold-bearing conglomerates make the mining in this area partake more of the nature of an industrial enterprise than is usually considered appropriate to mining ventures. This justifies the great attention that is paid to the engineering features of the work, and the large sums spent on the necessary mechanical equipment for the rapid and economical mining and reduction of the ore on a large scale.

According to the Transvaal mining laws, only the ore body contained vertically beneath the surface claim area can be mined by any given mining company. In order to exploit the ore contents of a mine situated at a distance from the outcrop, it is the practice, therefore, to sink one or more vertical shafts near the

* See "An Estimate of the Gold Production and Life of the Main Reef Series, Witwatersrand, Down to 6,000 Feet." By Messrs. T. H. Leggett and F. H. Hatch. Transactions Institution of Mining and Metallurgy. Vol. X (1901–2).

northern boundery of the property, to the intersection of the reef. This is then opened up by horizontal drives in the direction of the strike, and inclines along the dip; the principal inclines, in the most cases, being extensions of the vertical shafts. The ground thus opened up is stoped as required for the reduction plant, the development being kept ahead of these requirements sufficiently to permit of keeping up average values of the output, in spite of local variations in the gold contents of the ore body; and this process is continued until the payable ore body in the claim area is exhausted.

Where these vertical shafts are of moderate depth, the hoisting in both vertical and incline shafts is done by steam winders located on the surface, the vertical shaft being turned through a circular or parabolic curve into the incline. At greater depths, separate winders are used for the two sections (vertical and incline), but both located on the surface, the ropes for the incline hoists being led down the vertical compartments near one side, and suitably guided into the incline, the ore being transferred from one hoist to the other at the intersection of the two shafts.

Further extensions of the "Deep Levels" involve vertical shafts of 3,500 to 5,000 feet to the intersection of the reef, with inclines from this point of 3,000 to 6,000 or more feet in length; and in planning the development and equipment of these new properties, it is evident that present hoisting methods must be considerably modified. A recent paper by Mr. H. C. Behr* very ably presented the various features of this hoisting problem, and in this paper and the ensuing discussion will be found a very complete treatment of the matter from several points of view.

The concensus of opinion amongst South African engineers seems to be that these "Deep Levels" will be operated on an even larger scale than has obtained previously, the output planned for being 2,000 to 3,000 tons per mine per day; and that the greatest attention will be given to the economies that may be effected in working costs by the use of machinery, and in economic methods of operating the same. The advantages of electric power distribution are well recognized, and this method will be extensively adopted for what may be termed auxiliary power requirements. This is not an inconsiderable amount; it may be from 500 to 1,500 k.w. per mine, for surface requirements only.

* "Winding Plants for Great Depths." Read before the Institution of Mining and Metallurgy in London, May 15th, 1902, and before the South African Association of Engineers, in Johannesburg, August, 1902.

The underground workings will be arranged with a view to rapid removal of the ore contents, and it is probable that several incline shafts, operated by independent winding engines located underground, will be used to feed each single large vertical shaft, the latter having several pairs of hoisting compartments, and possibly arranged for hoisting in stages. In any case, there will exist within the next few years a demand for hoisting engines of considerable size, to be located underground in a dozen or more of the "Deep Level" mines, and with from three to six hoists per mine.

As in several cases a number of these mines in the same neighborhood are controlled by the same financial interests, and will require their equipment at approximately the same period of time, it is perfectly feasible to consider the supply to such a group of mines of their electric power requirements from a single central power station; and if these requirements are to include the underground hoists I have mentioned, it may be of interest to mention in a general way some of the conditions of the problem thus presented, and some of the conclusions that have been drawn therefrom.

In the first place: The principal power requirements of the mine equipment and the area over which the power is to be distributed (this being several square miles, with an added distance of in the neighborhood of a mile for each transmission to any underground installation) practically determine the use of a polyphase system at a moderately high voltage, especially as the ratio of copper cost to power cost is about twice as great in the Transvaal as in most countries, thus rendering the use of small line losses desirable.

However, I think it is generally conceded that, for hoisting work on the scale indicated, direct current motors are more suitable than alternating. Their use in this instance, therefore, involves apparatus for converting the polyphase supply into direct current.

In spite of the losses and extra first cost involved in this conversion, it presents many important advantages in connection with the control system and the central station supply, as I shall endeavor to show.

First, however, as to the nature of the power demand of such hoists as will be required.—

The hoists will be of the double drum type, with clutches for each drum; and while they will be operated normally in balance,

they must be capable of bringing up a fully loaded skip from the bottom with the other drum unclutched, *i.e.*, without the balancing effect of the empty skip and its rope.

While for each particular installation the size of the hoists must be separately determined to suit varying local requirements with regard to degree of inclination, load to be hoisted, length of haul, etc., the following may be taken as representing the approximate limits, between which particular values will be taken to suit conditions:

Load of ore 5,500 to 8,000 lbs.

Hoisting speed 2,000 to 3,000 feet per minute.

Degree of inclination 25° to 45°.

A hoist to suit what may be taken as average conditions would demand some 400 k.w. at the end of the acceleration period.

The hoists would be installed for an ultimate hoisting distance of perhaps 3,500 feet along the incline (any longer inclines being equipped for hoisting in stages), but would only have some 300 feet or so to haul when first installed. As the incline would be continued at the rate of about 100 feet per month, in about two and a half years the hoist would be working at its full capacity, and during most of this time would be operating under maximum conditions of load, the variables being the frequency and the duration of the trips, and possibly maximum speed if the control scheme be suitable.

Considering an individual normal trip, it is evident that the maximum torque required from the hoist motor occurs at the time of starting the loaded skip on its upward journey; for the acceleration is a maximum, the moment and friction of the ascending rope is also a maximum, and the balancing effect of the rope on the descending skip is a minimum. On completion of the acceleration period the effective torque still continues to decrease during the remainder of the trip, by reason of the winding up of the rope on the ascending skip and the corresponding unwinding of the rope on the descending skip.

The design of the hoist should not be such that this torque would become negative before the completion of the trip, as this would require the application of the brakes at this point to destroy all the inertia of the moving masses. It is obvious that this inertia should be utilized as far as possible to complete the last part of the trip, the brakes only being used to effect the final landing of the skip.

While similar in kind, the mechanics of this problem are quite

different in degree to those of operating elevated railway trains, the relative value of the kinetic energy of the moving masses and the work done against friction and gravity being quite different in the two cases. Thus, with the limitations to hoisting speed imposed by practice, a considerable part of the trip must be made with power after the acceleration is completed, and the "coasting" period only exists for the few seconds required to bring the moving masses to a standstill.

In considering the demand on the generating plant occasioned by such a trip, the form of the acceleration curve to be adopted is of importance.

Obviously, if the available acceleration moment is fixed, maintaining the moment at a constant (maximum) value throughout the acceleration period gives a minimum duration of that period; but, as pointed out by Mr. Behr in the paper previously referred to, an acceleration showing a constant decrease from the same maximum value to zero will give the same ultimate velocity in a certain space, and requires only 5 per cent. greater time than is needed to cover the same space with the same maximum velocity using an acceleration maintained constant at the maximum value.

The maximum power actually demanded by the hoist motor during a given trip depends upon the form of the acceleration curve, and is materially greater with constant acceleration than with constantly decreasing acceleration. The power demand being proportional to the product of the total torque and the speed at any instant during the period, it is evident that as the constant acceleration maintains the initial maximum torque until the maximum speed is reached, the power demand continually increases during the acceleration period, and at its end is a maximum. With a constantly decreasing acceleration, however, the maximum torque only occurs at minimum speed, and at maximum speed the acceleration torque is zero; therefore the maximum power demand occurs at some instant between these two points, and is but little greater than the power demand at full speed after acceleration ceases, which is that required for overcoming the effects of friction and gravity only. The actual amount of the work done is of course practically the same in either case.

It is evident that the constantly decreasing acceleration is much more favorable to the central station, in that it gives a better load factor, less fluctuation in the power demand, and requires less investment in generating plant, provided the method

of control is such that the power demand from the source of power is proportional to the actual power demanded by the hoist motor.

The control system is thus the important factor in attempting to realize these advantages, as the *decreasing acceleration* is more normal for electric motor operation than the other; and for this purpose I know of no other method of control that is workable than some form of " voltage control " or " Leonard " system. Involving as this does some separate dynamo machinery for each motor installation, the advantage in control method previously referred to in connection with the conversion from the assumed polyphase distribution to direct current becomes apparent, in that this converter machinery may be utilized in one of a number of obvious ways to furnish the " voltage control " of the hoists.

This machinery also helps out the central station in another way, in that the inertia of its moving parts further smooths out the peaks in the demand curve during each trip; this effect may even be increased by the deliberate addition of inertia to the converter set in the form of a fly wheel, as has been proposed by several Continental engineers that have investigated this problem*.

The " voltage control " also possesses incidental advantages. The necessary slow speed inspection trips in the shaft may be readily made; during the first year or so of operation, the controller can readily be provided with adjustable stops limiting the maximum speed (consequently the maximum power demand) to whatever amount will give the desired output, and thus again improve the central station load factor; the controller need not handle the very considerable main current of the motors, thus eliminating a source of considerable first cost, and also maintenance cost; given positions of the controller handle result in nearly enough given speeds, irrespective of loads. These characteristics are so well-known that is perhaps superfluous to mention them here; I only wish to indicate that in almost every particular this problem is best met by this control scheme, which favorably affects both the source of the power and its utilization.

I have only stated the conditions in a general way, without particular data as to details, for much of the data has not yet been definitely determined, and would necessarily vary with the different local conditions of different mines. I trust that in

* See " Electric Winding Problems," by Mr. H. Spengel, Transactions South African Association of Engineers, 1902.

spite of this, I have justified to some extent the conclusion that for this important hoisting work, the best method is the combination of polyphase transmission, conversion to direct currents separately for each hoist unit, and the utilization of the conversion machinery for obtaining suitable control of the hoisting operations by the " voltage control " or " Leonard " system.

PRESIDENT SCOTT:—I had the pleasure of meeting Mr. Pierce when he was in America a few years ago, and it is unfortunate that we have not time for discussion of the paper at present, as it is certainly a valuable contribution.

FRIDAY—JULY 3, 1903.

PRESIDENT SCOTT:—The meeting this morning is a joint meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS and the Society for the Promotion of Engineering Education. Professor Woodward, of Washington University, St. Louis, the President of the other Society, is on the platform, and I take pleasure in presenting him to the INSTITUTE.

Part of the papers are contributed this morning by members of the INSTITUTE and part by members of the Society.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

THE TEACHING OF PHYSICS TO ENGINEERING STUDENTS.

BY W. S. FRANKLIN.

I have been teaching physics to college and university students for nineteen years and I now have a few ideas on the subject which can, I think, be expressed independently of the subject-matter and which may be helpful to others.

Some time ago, in talking with a practical engineer on the teaching of physics, I stated that in my opinion the ultimate object of the teaching of physics to technical students is to lead the young man by a shortened route to that familiarity with physical things which is possessed by such a man as John Fritz. The shortening of the route which leads to this result depends upon the fact that the teacher of physics has to do largely with an *epitome* of real knowledge, and consequently the primary object of physics teaching is, in my opinion, to develop in the young man's mind a logical structure consisting of the aggregate of physical conceptions and theories.

Since beginning the teaching of physics, I have never devoted any of the time of my classes to the discussion of the history of the subject. The best way to study an organic structure is to study its history, through the medium, say, of embryology, but this is the worst possible way to study a logical structure.

I have never on any occasion apostrophized the Wonders of Nature to any class of mine. The ability to measure electricity and the ability to calculate magnetism are really very simple and prosaic things, and any writer or teacher who for a moment allows himself to speak of these things otherwise than in explana-

tion or in application, may be set down at once as attempting to lend an element of mystery to knowledge he claims to possess. It seems to me a very significant fact that in most of the cases that have come to my notice, the appeal on the part of a scientific writer to the reader's wonder-sentiment has been associated with very hazy, or entirely faulty, notions on the writer's part. I know of a text-book on physics which introduces the discussion of the doctrine of the dissipation of energy in the chapters on Mechanics: this text-book actually would have it appear that the degradation of energy is *essentially the change from the potential to the kinetic form*, and the whole discussion ends as follows: "Tait calls available energy *Entropy*. The inevitable conclusion is that *entropy tends toward a value of zero*. 'In the beginning, then, points to a period when all energy was available. With no less certainty, physical science points to a time when entropy shall become zero. All the processes of nature must then cease. Even the earth itself, as lifeless as the moon, can no longer circle round the glowing sun, but both and all together, in one dead mass, must hang in everlasting silence in the boundless night of space." Now, what I want you to keep in mind, is that this wonderful view adown the corridors of Time is ostensibly based, in the book in question, upon a succession of egregious blunders.

I never have allowed the slightest sepculative tendency to enter into any of my teaching, oral or written, and the extent to which many of our elementary text-books in physics indulge in imaginative nonsense and in weak phases of speculative philosophy is distressing to me. Nearly every text-book on physics that I know of defines the mass of a body as "the quantity of matter the body contains." I had the pleasure thirteen years ago of listening to a course of lectures by von Helmholtz on theoretical physics, and the first eight weeks or more of this course was devoted to the origin and meaning of our quantitative methods in physics. I thought at the time that von Helmholtz's statements were so simple and so apparently remote from the usual complications of physics that most of his hearers were likely not to appreciate what he said. Those lectures, however, stand in my mind as the most complete outline of the philosophy of the mathematical sciences ever given. All our notions of length and angle arise from and are defined by the fundamental geometric *operation* of congruence. The definition of mass is also a *physical operation*, the verbal definition is the briefest possible specification of this operation. The result of this opera-

tion on a given body is an invariant number, and by a feat of the imagination we are led to adopt this number as a measure of the "amount of matter the body contains." This is a notion of some mental utility although strictly it is mere imaginative nonsense. Several years ago I had occasion to review a well-known French book on "Electrical Measurements," the authors of which say "Une grandeur est une quantité susceptible d'augmentation ou de diminution. Une grandeur est dite mesurable quand on peut la comparer à une grandeur de méme espece et que la résultat de la comparison donne à notre esprit une satisfaction compléte."

As an example of weak speculation, what do you think of the use in a *secondary school book* on physics of the following quotation from Maxwell as a means to clear up an inadequate discussion of energy? "We are acquainted with matter only as that which may have energy imparted to it from other matter, and which may in its turn communicate its energy to other matter. Energy, on the other hand, we know only as that which in all natural phenomena is continually passing from one portion of matter to another." What do you think of the following from an elementary English text-book on physics? "The fundamental property of matter, which distinguishes it from the only other real thing in the universe, is inertia. * * * We are now in a position to give one or two provisional definitions of matter—provisional because we cannot yet say, possibly may never be able to say, what matter really is. It may be defined in terms of any of its distinctive characteristics. We may say that matter is that which possesses inertia, or again since we have no knowledge of energy except in association with matter, we may assert that matter is the Vehicle of Energy." I wonder if any of you really doubt that every notion in physics, definite or indefinite, is associated with and derived from a physical operation, and that absolutely the only way to teach physics to young men is to direct their attention to that *marvelous series of determining operations which bring to light those one-to-one-correspondences which constitute the abstract facts of physical science.* If you do doubt this, I am bound to say that I do not think much of your knowledge of physics. I think that the sickliest notion of physics, even if a student gets it, is that it is the science of masses, molecules and the ether. And I think that the healthiest notion, even if a student does not wholly get it, is that physics is the science of the ways of taking hold of bodies and pushing them.

In my opinion, the characteristic feature of science study, especially of the study of physical science, is *a determining objective constraint upon the processes of the mind.* I am surprised that this one important feature of science study is never mentioned in the many estimates that have been made of the value of science study in education, for as a matter of fact, that *complete definiteness* which is usually urged as the characteristic and valuable feature of science study is the fundamental condition of every psychological process, you say this or you say that, you go or you do not go, and even the classic mule standing midway between two similar loads of hay is in no danger of starving from indetermination. The psychological processes which are brought into play in the study of science do not differ from other psychological processes in regard to definiteness.

I say again that it is the completeness of objective constraint that chiefly differentiates the study of the physical sciences from all other studies and which makes the study of the physical sciences so important an element in any correct scheme of education. The importance of this objective constraint upon the mental processes in scientific work is most strikingly shown by the entire absence of any such constraint in all of our crank scientific literature. I think that the full realization of this objective constraint in the teaching of physics depends first of all upon the making of one's teaching utterly and absolutely simple and homely, *and devoid of all appeal to anything but the rigors of the scientific imagination.* Anything beyond this is, in my opinion, idolatry.

I think that the ability to learn science by reading is a highly specialized faculty and that among average young men this faculty is nearly zero. I know many men who are quick to receive knowledge by experience, and quick to catch, from verbal description, manifold variations of their empirical knowledge, but whose imagination is wholly unresponsive to that abstract kind of writing which is so necessary in a concise treatise on the elements of physics.

Nevertheless, I think that the development of the student's imagination to the extent that is necessary to enable him to follow concise writing is one of the chief objects in the teaching of physics, and I do not believe that this result can be accomplished without requiring the student to use a text-book of the severest kind.

My idea of the teaching of physics is to use a sharply, clearly

and concisely written text-book, to give explanatory lectures of such character as to appeal properly to the student's imagination (*theoretical lectures*, in fact, illustrated by the simplest kind of experiments), to require of the student a large amount of numerical calculation, and to give a laboratory course based upon highly generalized printed directions supplemented by a vanishing series of verbal suggestions from an instructor.

I think that the chief object in a course in physics for technical students should be to give conceptual and analytical knowledge of the most important facts of physics. It is certainly better to know a little by reason, than much by rote. There is nothing in the teaching of physics so important as to develop in the student the ability to express physical conditions in mathematical form, geometrical or algebraic as the case may be, to reproduce or re-present the conditions of a problem adequately as a geometrical construction or as an algebraic formula. Nothing, I think, is so important as this for technical students. It is the very essence of effective knowledge of physics, and every bit of attempted instruction in physics which does not contribute directly or indirectly to facility in this re-presentation of physical fact in terms of our mental tools is in my opinion futile.

Many students and even teachers of physics raise the objection that a rigorous mathematical presentation of physics is highly unsatisfactory and uninstructive. They like such a book as the excellent new book of Edser's on *Light* which abounds in descriptions of phenomena and of the most recent researches on light pressure and the cause of comet's tails. Now, I am really interested myself in comet's tails, but I would feel like thrashing a young student who concerned himself about comets' tails and held his imagination unresponsive to a discussion of stationary wave trains and of reflection with and without change of phase. I have a contempt for a student who thinks he understands the formation of a comet's tail but admits that such things as the kinematics of wave motion are beyond him. I recommend such a student to be honest with himself and study physics under the instruction of Jules Verne. Then he need not trouble himself about foundations, but he may follow his teacher pleasantly on a careless trip to the moon and with easy improvidence embark on a voyage of ten thousand leagues under the sea.

In my teaching of physics I have come to distinguish two distinct phases of laboratory work. One phase is that which is intended primarily to vivify algebraic formulas—I think it is silly

to talk of the verification of Nature's Laws (!) by a student—and the other phase of laboratory work consists of elaborate and precise measurements carried out with every possible precaution for the elimination of error.

I take pleasure in distributing to the INSTITUTE members here present a small pamphlet which I have had printed for this occasion as an illustration of the vivifying phase of laboratory work. The eight experiments described in this pamphlet apply to the direct current dynamo, and I think that every technical student who studies physics to any extent should perform these experiments just to see the equations of the dynamo become alive. No one really knows much physics who is not able to look at an equation and see the manifold activities which the equation is intended to represent.

DISCUSSION.

PRESIDENT SCOTT:—The paper of Professor Franklin, which presents the subject of teaching physics in a manner that is certainly quite different from the old idea, is now open for general discussion.

PROFESSOR GOLDSBOROUGH:—If I catch Professor Franklin's idea correctly, what he means is that the boys should have a thorough and complete drill in theoretical electricity and then they should be taught to apply that theoretical training in practical work, and not be sent out of college with a theoretical training and a practical training which to the student have no relation the one to the other. Referring to what Professor Franklin says as to the equations of the dynamo, why, there are lots and lots of young men who know the equations of the dynamo and who know the equations of alternating current circuits, but there are comparatively few who feel thoroughly acquainted with them; they know them in a vague kind of way, but their ideas are involved and not made a part of themselves. Too much care cannot be taken to have students pass into professional life with the proper "joint" between the theoretical and the practical. This requires skill on the part of the instructor in putting the student through the right "soaking" process. It is a perfect farce for us to introduce empirical formulas into electrical engineering. There is hardly a problem which we cannot solve with the use of a rational formula. Students very frequently come to me who have had training in certain mechanical subjects in which it is absolutely necessary to make use of empirical formulas. They then want to jump to the last formula on the page, which shows the result, and "substitute" in that formula. I always make them go right back to the beginning, to the start and go right down through, until they get what has gone before, and until they master this I do not think they have any business discussing the result.

PROFESSOR LANGSDORF:—My own experience in teaching dynamo laboratory work is not quite as long as that of Professor Franklin, but it has been long enough to show me that there are two ways of conducting the work. One method is to give the student at the beginning the equation which represents the relation between the quantities which he is to measure, and then have him verify it by substituting therein the numerical data obtained in the laboratory. The other method is to give him the apparatus, tell him to take the data, plot his curve, and then finally determine the equation from the curve.

I think that by the latter method the thing is impressed upon the student as it can be done in no other way. I remember that in my own experience as a student, when I had to derive the complete equation of the bifilar pendulum, it took on a meaning which blind acceptance could not have given to it; and it is this method which I have always used with my students.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

THE PROBLEMS THAT ARE FACING THE ELECTRICAL ENGINEER OF TO-DAY AND THE QUALITIES OF MIND AND CHARACTER WHICH ARE NEEDED TO MEET THEM.

BY J. G. WHITE.

Since the title assigned for this paper contains more than one per cent. of the total number of words allotted, there seems little room to speculate as to the problems confronting us.

To some engineers apparently the one and only problem is that of salary, while for others the greatest problem is to find men who *can* and *will* earn large salaries.

Other problems range from figuring the proper size of an electrical conductor or tracing out a telephone circuit up to the highest speculative imaginings of which the human mind is capable, such as those suggested by the recent statements of Prof. Crooke's, Prof. and Madame Curie and others, regarding the atomic theory.

We are now told that each atom, formerly considered indivisible, is a whole stellar system, composed of a tremendous number of absolutely identical units, all in orbital motion.

We are further told that of these identical units or ions, an atom of oxygen contains 11,200; an atom of gold 137,200; an atom of radium, 120,000; and so on.

Who can delineate the problems which will be presented by this new theory, or by the strange properties of the recently discovered radium and other radioactive substances?

A recent article on this new development says: "Chemistry has in fact become the astronomy of the infinitesimal. One is led to wonder then if the earth and the other planets are not mere ions forming a single atom of a higher universe, where perhaps they constitute a speck of dust that worries the careful housewife in the world next above us."

As, however, this is a body of educators and engineers rather than of astronomers and philosophers, may it not be well to avoid speculation and be content during the brief time at our disposal with what might be called a " plain 3 per cent. investment? "

The qualities of mind and of character needed by the electrical engineer of to-day are too well-known to need to be specified.

He should be *accurate* in his calculations, *thorough* in his investigations, *logical* in his deductions, *lucid* and *concise* in his statements.

He should have *untiring energy*, an *alert mind*, abundant initiative, and *reasonable self-confidence*.

He should be absolutely *honest* in all his dealings, *truthful* in all statements, *loyal* to his clients, *faithful* to his employer's interests, *considerate* of his subordinates, *diplomatic* in his negotiations and *tactful* in all his relations.

However, instead of attempting to rear a structure on the foundation of the text assigned to us, may we not rather use it as a spring-board from which to vault into the general field under discussion to-day?

This might be summarized under the title, " What education should the electrical engineer of to-day have."

In entering this field, I realize that I may be trespassing on the preserves and vested rights of Messrs. Gherardi, Osborne and Johnston, whose papers are to follow:

In that case I hope these gentlemen will follow the example of the beasts in Kipling's Jungle Stories, and wish me " Good Hunting."

Irrespective of this, there are a few points in the education of an engineer which are so important that it would probably do no harm if they should be repeated and urged by every one of the men to whom papers for to-day's session were assigned.

One of these points is well covered by Mr. Johnston's paper, " Engineering English," the great importance of which is further emphasized in the latter part of this paper.

As is frequently remarked, this is the age of great industrial combinations and of specialists. Not satisfied with this, the specialists now specialize. The engineering field was formerly divided into the two general classes of military and civil engineers. From the latter gradually developed marine, mining and mechanical engineering, and as an offshoot from this last branch, there was recently added electrical engineering. Civil engineers to-day are sub-divided into such classes as hydraulic engineers, bridge engineers, railroad engineers, etc. We also find that electrical

engineers are classified as telegraph engineers, electric light engineers, electrochemical engineers, telephone engineers, etc.

A few years ago many of us would have supposed that the problems of the telephone engineer were those of a high-class artisan and that they would consist largely of trying to unravel tangled cobwebs of fine wires, and to understand and to be able to operate mazes of signalling, connecting and protecting devices. A member of the INSTITUTE OF ELECTRICAL ENGINEERS, who is the head of the electrical engineering school in a prominent university, remarked not long ago that he never appreciated the importance of the telephone engineer until he saw one of the particularly well-known members of the profession decline a salary of $25,000 a year. The professor further stated that ever since then he has wished he knew enough to be a telephone engineer.

In the early days it was thought that a room of almost any shape and size, with a couple of empty boxes for seats, and a switchboard of primitive design and construction was all that was needed to make a telephone exchange. The City of New York had in 1894 about 10,000 telephones or "stations"; in 1900 the number was about 45,000; at present, the number is in the neighborhood of 100,000, an increase of 1,000 per cent. in nine years, and by 1910 it is estimated the number will be perhaps 300,000. These figures are understood to be exclusive of desk or other extension sets.

Owing to the wonderful growth of their business, telephone companies now erect buildings specially designed to meet the requirements of their exchanges, and a telephone engineer must know something of architecture, the strength of materials and other factors entering into modern steel building construction, and many other subjects which should be a part of a broad engineering education, but which are not ordinarily supposed to come within the province of a telephone engineer, as narrowly applied:

It is at least equally important that other engineers who have specialized and must know well some part of the field of engineering should likewise have a general knowledge of the sciences and of the broad underlying principles of engineering, based on a thorough mastery of elementary mathematics and supplemented by some study of languages, history, civics and other studies of general educational value.

The question naturally arises, how can the engineering student

possibly obtain a satisfactory knowledge of all of these important subjects? Much of his special knowledge must be acquired after he has commenced the practice of his profession. If unusually energetic and capable, all or any part of his education may be gained after he enters professional life, but it is preferable that his broader education be well started during his school years. For a considerable time it has been clearly recognized that law and medicine require, for general and special study, more time than is possibly available in the ordinary college course of four years. The well-educated lawyer of to-day takes a thorough preparatory course, four years in college, and three, or at least two, years in law school, and after this is likely, if he can afford it, to take one year abroad or in some special post-graduate work. The well-educated physician of to-day after regular and preparatory courses, spends three years in medical college, and if possible, one year in foreign study, and then is likely to devote several years to hospital work, before attempting to engage in the general practice of his profession.

If lawyers and doctors can afford the time and money necessary to get such educations, should not engineers, in view of the very wide range of subjects with which they must now be reasonably familiar, adopt a similar plan? The decision of this question will have to be made individually by the young men themselves, important factors being the time and money available for educational purposes.

It is well to remember, however, that more important than a knowledge of any study, or group of studies is the ability to master *thoroughly* any subject of which a knowledge is desired.

In education especially, quality is more important than quantity. A thorough mastery of arithmetic and algebra is better than a mere "pass grade" knowledge of these and all the higher mathematics, which is then ordinarily soon forgotten.

It is better never to have seen the inside of a Latin, French or German grammar, and to use correct English, than to have the ordinary three or four years "translating knowledge" of all three of these foreign languages and still say "I seen."

As in nearly all practical engineering problems, this one of engineering education can perhaps be best set forth by arranging a balance sheet showing the credit and debit sides. Against the extended education we have expense involved, time necessary before the earning period is reached, time required for general study which might be devoted to mastering some special branch of engi-

neering, thus more quickly insuring a comfortable salary, danger to health if too much study is crowded into a given period, etc. On this side also we have the danger that by widely extending the field of endeavor we may produce a student rather than an engineer, or that the work may be superficial. The *importance of thoroughness is supreme.*

This implies also that the education of the engineer must develop not a dreamer, but a worker, thoroughly competent in his sphere, whether great or small.

It is better for the world and for the man that he should be a high class mechanic or artisan, with a good common school education than that he should be nominally an "engineer," having a smattering of many subjects, and ekeing out an existence amongst more competent fellows.

It is better for him never to have been inside a college, but to have commenced at wheeling ashes and become a good electric light superintendent, than that he should "drag" through college and university, take master's and doctor's degrees and become an incompetent college professor. His social status may not be as high, but he will be a more useful man.

On the credit side of the extended education we have, first, the direct satisfaction to be had from its possession and the ability to enjoy on even terms the society of educated people.

Secondly, there is the practical use to which this knowledge can be put.

Thirdly, and more important than the knowledge actually acquired, is the learning how to *know* a *subject*, and where or in what direction to look for information specifically wanted.

Fourthly, there is the certainty that with equal industry and attention to his work, the young engineer of ability with a broad education will ultimately take higher rank in his profession and be more successful in business.

The qualified phrase, "young engineer of ability" is used advisedly. The engineer of ordinary or less than ordinary ability, will, in practical life, accomplish most by not attempting to have his education cover too wide a field, and learning some special department thoroughly.

A prosperous market gardener is more to be envied than a poor farmer.

If a young man will take for his motto "thoroughness," and, in planning his list of studies, will include first those of prime importance, and then add those of decreasing importance until

all his available time is occupied, he will be planning most wisely. Ordinarily the young man will not be able to arrange a course entirely to suit his individual requirements, but he can use the method above suggested to help him in deciding as between various courses offered. The choice should, when time and mental capacity make it possible, be in favor of a broad general education, supplemented by thorough technical training. This may, and frequently will, lead to a general college course to be followed by a technical course of two or more years.

The writer recently knew of two groups of men who were each looking for an able street railway manager, and who were willing to pay in each instance a salary of $25,000 per annum. The man who happened to be offered both of these positions is said to have been for 12 years a street car conductor. This is no proof that an engineering education is valueless. It is, however, conclusive proof of the *superior importance* of *good business judgment* and the ability *thoroughly to master a given subject*, which in this instance happened to be street railway operation and management.

People are to-day looking for engineers and would gladly pay salaries of $6,000 to $10,000 per annum for men of exactly the right qualifications. It would be easy to find hundreds of men who have had all the necessary general education, and scores who have had as well all the needed technical training. The questions which are asked, however, are such as the following:

Has he good business judgment?
Has he tact?
Has he the mental capacity and breadth to develop into a "big man?"
Is he diplomatic, with ability to negotiate?
Is he initiative, without being erratic?
Will he get results?

We might divide the studies which are worthy the attention of the electrical engineer into four general classes. Individual opinions will necessarily differ widely as to the studies which should come within each class. Some will want to increase and others diminish the total number. In any event, the student should attempt studies of the relatively less important classes only in case he has already mastered thoroughly, or is sure of so mastering, the more important studies.

In the first class we may put those studies which will teach to *think clearly* and *express lucidly*, which will *teach how to learn*, and which will give a comprehensive knowledge of the fundamental

facts and principles underlying his profession. These should be learned most thoroughly, and would include English, arithmetic (*mental* and written), algebra, geometry and trigonometry, chemistry, physics (especially mechanics), general knowledge of principles of electrical engineering, practical ethics.

The second class may include *some subjects* which will especially tend further to develop clear thinking and clear writing, some which will further increase the knowledge of the general principles of his profession, and some which will give knowledge that will be professionally and commercially useful. This class includes: Calculus and vectors, surveying, Latin (usual preparatory course) French (speaking and reading—not translating knowledge of), electrochemistry, advanced engineering studies, business law, general principles of modern accounting, civics.

The third class may include some subjects which are likely to be of direct professional or commercial use, and others, the study of which will be of general educational value. This class includes: Spanish, geology, physiology and temporary care of injured; logic, quaternions and subjects which are studies of engineering details rather than of general principles, etc.

The fourth class may include those studies which will help in rounding out the education of the man rather than in furnishing the essential equipment of the engineer. This class includes: Mineralogy, botany, zoology, history, political economy, mental and moral philosophy, art, music, etc.

The third and fourth classes of subjects are useful to round out and complete the foundation and frame work provided by the first and second classes, but should not be indulged in at the expense of the relatively more important. A few non-technical subjects merit individual mention.

English.

President Butler, of Columbia University, is reported to have said: "The first two evidences of an education are correctness and precision of speech, and refined and gentle manners." The latter must be acquired almost entirely at one's home and from contact with one's associates. The correct speech must be acquired largely in the same way, but may be learned to a considerable extent, in the preparatory schools and in the college or university. There is nothing more important for the young engineer to learn than "the skilful and correct use of language, whether to state a fact or convey an idea," understanding that "clear thinking precedes clear speaking."

English should be taught from beginning to end of the preparatory school work, and also from beginning to end of the college course. In order to have this drill continue throughout the college course, it may be necessary to have a considerable part of the training incorporated into the writing of *laboratory reports*, *examination papers* and other similar documents. Is this not feasible? Whether done in this way or not, the training should be continuously maintained

Arithmetic and Algebra.

More attention may well be paid in the preparatory schools to algebra and arithmetic, especially *mental* arithmetic. A comprehensive understanding of algebra is most useful to the engineer both in his later studies and in practical work. Mental arithmetic provides both good mental exercise and equipment.

We sometimes hear engineers, as well as others, speak of the "poetry of motion." Many of our profession seem to understand this, only as applied to the slide rule. It is unnecessary, and is frequently annoying to have an engineer who is drawing a salary of several thousand dollars per annum pull out his slide rule, and, after some considerable manœuvring, announce that "5 times 4½ is about 22," or that "two tons of rails at $33 per ton will cost *about* $65."

Surveying.

During the college course it would seem advantageous even for the electrical engineer to devote a moderate amount of time to the study of the various methods of surveying now practised. These can be quickly understood if the student has thoroughly mastered his arithmetic, geometry and trigonometry, and a general knowledge of surveying is very likely to be useful in practical work. The summer spent on railroad location and construction will help develop one's physique, teach one to read and fully appreciate a profile, give a little knowledge of construction costs and methods, and give other knowledge which one will probably find useful in both field and office. A summer so spent will in after life be remembered as time well and profitably occupied.

French and Latin.

French and Latin are included in the second class, because of the mental training and polish to be gained by their study. Some knowledge of Latin will greatly assist in thoroughly mastering English, and is in this respect more useful than the study of German.

A knowledge of French which will enable the young engineer to speak and read with ease is strongly recommended. The educated people of Mexico, South America, Russia and other countries speak French, and as this for centuries has been the polite and diplomatic language of the world, the advantages to be derived from mastering it are likely to be not only educational and social, but commercial as well.

On the contrary, there is little prospect that American engineers can practise their profession profitably in Germany or German-speaking countries. Nearly all important scientific papers are now promptly translated into English, and included in the technical press or publications of the various scientific and engineering societies. In consequence, there is no longer any special need of the engineer knowing any foreign languages for the sake of keeping advised as to the progress made in the work of his profession.

The general educational value of learning one modern language seems about equal to that to be gained from learning another. Consequently, the social and commercial advantages of French give it first place for the American engineer.

Spanish.

The study of a second modern language should be undertaken only in case the first can be spoken fluently. Then it would seem that Spanish is the best language to learn. Having studied Latin and French, Spanish should be very easily acquired.

The development of Porto Rico, Cuba, the Philippines, Mexico, the Central and South American countries will probably afford many opportunities for the engineers of the coming generation, and to these a knowledge of Spanish would be of great value.

Engineering Studies.

The time devoted to various engineering studies in Class 1, as well as in Class 2, must depend largely on the facilities of the college attended, and the special work for which it is intended to prepare. It would be quite useless to attempt to discuss the relative importance of the purely technical studies in the time at our disposal, or to attempt to arrange any detailed plan of technical work.

Business Training.

Somewhere in the general course there should be included a moderate amount of training in modern business methods and practices. There is no more reason for the engineering graduate being utterly ignorant of even the most elementary

knowledge of business practices than that he should know absolutely nothing of geography.

Accounting.

All engineering students should have some reasonable training in accounting, so that they would not be entirely ignorant and without power of speech if, after beginning the practice of their profession, they are asked some elementary questions about the annual report of a street railway, electric light or manufacturing company.

Business Law.

A moderate amount of time should also be devoted to the study of fundamental principles of business and corporation law. An engineer, in practice, should at least be able to draw a contract which will be legal and explicit.

In General.

A modern engineer is dependent for his success largely on the financier. If the engineer does not know that bonds should pay interest, and that stocks, if possible, should pay dividends and has no conception of the difference between a stock certificate and a promissory note, the financier is likely to form an undeservedly low opinion of the engineer's technical knowledge.

If a young engineer will have before him constantly the ultimate and best interests of his employer, will endeavor always to be tactful and never unnecessarily to irritate, will—without flattery—say only what is pleasant, unless right demands a plain statement of an unpleasant truth, then his advance will surely be more rapid than if these things are forgotten or neglected. The importance of these things should be pointed out and frequently emphasized by educators.

The technical problems which face the engineer are certain to be recognized as they come up. Too frequently the importance of problems connected with one's business and social relations with employers, fellow employees and others are not appreciated. These deserve careful and persistent study. Their correct solution and an accurate appreciation of the proper proportion of things, constitute business sagacity. The paramount importance of such matters should be repeatedly impressed on students and they should be led to understand thoroughly that their satisfactory solution will be rewarded not only by a pleasanter life during working hours, but also by increased esteem and greater business success.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

THE PROPER QUALIFICATIONS OF ELECTRICAL ENGINEERING SCHOOL GRADUATES FROM THE TELEPHONE ENGINEER'S STANDPOINT.

BY BANCROFT GHERARDI, JR.

I have been asked by the Chairman of the Papers Committee to say a few words on the proper qualifications of electrical engineering school graduates, judging them from the point of view of the telephone engineer.

These qualifications are the product of two factors: the natural ability of the man himself and the training which he receives at the engineering school.

Upon the man's natural ability, although a factor of prime importance, I will not, owing to the limitations of time, attempt to speak in detail here to-day. In general terms the nature of these natural qualifications, which seem to me to be requisite in the engineering student, is evident from a consideration of the training which the school attempts to give him, for if he is to obtain anything of value from his school training, he must have those qualities of mind necessary to enable him to assimilate it.

In treating my topic, I shall confine myself to a discussion of the subject of education considered not primarily with reference to preparing the student for his general responsibilities with reference to society, but solely as providing him with the special qualifications needed in his professional work.

In thus excluding from the present consideration the question of what education should be given to the student for other reasons than to fit him for the special work of his profession, I do not wish to belittle the very great importance of broadening studies. A discussion including this phase of engineering education would extend my remarks beyond the time assigned to me,

would develop age-long controversies and would, perhaps, after all, be more suitable for discussion elsewhere than at this meeting. Even that branch of the subject to which I have restricted myself is so extensive that it will be impossible here to treat of it exhaustively and at best I will only be able to bring out a few ideas which have impressed themselves upon me as being worthy of serious consideration.

It is well recognized that telephone engineering is one of those specialties into which electrical engineering in general is rapidly splitting, and in consequence of this fact, it has been assumed by some that the school training for the telephone engineer should be different from that given to electrical engineers in other branches. That the telephone engineer should receive at the engineering school a training substantially different from that given to electrical engineers in other branches is a proposition with which I do not altogether agree.

While the professional work required of the telephone engineer, comprehensive though it is, bringing him in contact with various practical problems which do not confront electrical engineers in other branches, his work is, after all, based upon the essential principles which underlie the work of all of those engaged in the electrical engineering profession. It deals with the same materials and the same physical laws and it has the same general object in view; that is, to accomplish the most satisfactory results in the most economical manner.

If, in the few short years which are available for the professional training of the student, it were possible to teach everything in science and engineering which might be available in his professional work, it might then be reasonable to incorporate as a part of such training a large amount of work on problems particularly concerning the telephone plant and the questions which arise in the construction and operation thereof. It is evident, however, that to include in the curriculum such a course of training would far transcend the limits of time which the student can spend at the engineering school. It seems to me, therefore, that instead of attempting to teach these ultimate practical problems, the important matter is that engineering students should have discipline in the methods of solving engineering questions. Such discipline as I have in mind is not given by teaching him the solution of each and every question that may arise in practice, even if the time available would make this possible. On the contrary, this discipline can best be given to him by a general

training which will enable him to solve any question that may arise when he becomes acquainted with the conditions of that special problem. When the special problem comes before him, he will, with the proper training, be able to solve it first by getting the facts in the case and then by interpreting these facts according to correct processes of reasoning.

In my mind, therefore, the functions of technical education may be summed up as follows: Train the student so as to convince him of the necessity of getting his facts and teach him the best method of getting the facts. Train him as to the methods of interpreting engineering data and in reasoning thereupon. You will note that I do not say that the education should teach a man the facts. It seems to me it is evident to anyone who considers the question, that no course of college or university education can teach a man the facts and practices of such a field of engineering as we have under consideration. I do not refer to fundamental facts and laws, but refer to the details of superstructure with which so many special courses endeavor to familiarize a man before he starts on his professional career.

The state of the art in the case of any branch of engineering is necessarily voluminous and involved and is constantly undergoing rapid changes. The mere acquiring of such voluminous data and ascertaining their correct relations to other data is the work of a lifetime, even assuming that such data were available in a form which would permit of their being taught in a college or university. Furthermore, and what is more important, the attempt at teaching such data in the length of time available necessarily results in the neglect of those fundamental and general studies, the importance of which I am endeavoring to bring out.

If I were to consider the extent to which broadening or liberal studies should be required of the student, the question of how much time should be devoted to English literature, to logic and to philosophy, would require most careful consideration, but upon one point which might properly come under the head both of broadening studies and special technical equipment I have firm convictions. I shall speak of it here merely as part of the technical equipment of the student.

I am satisfied that extraordinary efforts should be made to teach every engineering student to write a report or letter in clear, convincing English, setting forth the facts and arguments and conclusions pertaining to any question he may have to con-

sider. The student should be taught to state in correct and logical form the nature of any given problem and to enforce his conclusion with arguments which must be convincing. Such training as this is not one merely in literature, composition or rhetoric; for it should be borne in mind that to write such a report as I have indicated, the student must, first of all, have mastered the problem itself, and that clear thinking must precede clear writing.

From this point of view discipline in English is not to be regarded as producing mere literary polish, but as enforcing correct thinking in regard to each and every question upon which he has to write. If rigidly applied throughout all of his college course, this will do more than any other single form of discipline to develop correct habits of thought.

In mathematics the usual training leading up to and including the calculus is sufficient for general engineering work in telephony, although it is well for men having special aptitude in mathematics to carry their work sufficiently far so as to be able to handle problems involving differential equations. The relatively small number of questions in practice, however, demanding this knowledge of higher mathematics, does not justify requiring it of every graduate, particularly as those not having aptitude for it would not be able to make much use of it in practice. A student should receive a good training in elementary physics and analytical mechanics, and should be familiar with the application of analytical mechanics to engineering problems. In electricity, the student's work should of course be carried much further than in the other branches of physics, and he should have a thorough knowledge of both direct and alternating currents. In addition to giving him this knowledge in the abstract form it should also be taught in some of its principal applications to the several branches of electrical engineering.

In experimental laboratory work he should have a fair amount of experience. This laboratory work should be chosen primarily as illustrating and proving fundamental laws and also as giving the student the necessary manual dexterity needed in handling instruments of precision. As an important part of such experimental work, I suggest that all electrical engineering students should be thoroughly drilled, not only in general electrical testing, but in the special electrical testing of cables and wires, having regard to their dielectric resistance and electrostatic capacity, as well as to their dielectric strength and other essential physical

and electrical properties. Such experimental work should also include some fundamental tests of prime movers as well as standard tests upon generators, motors, transformers and primary and storage batteries.

In the time allotted for this laboratory work, a due proportion should be set aside for selected experiments relating to the telegraph and the telephone. The student should also receive a general knowledge of the materials used in engineering work, both from instruction and from laboratory tests.

In the matter of shop practice, I think it is easy to run to excess. A certain amount of practical experience in shop work should be given to the student so as to familiarize him in a general way with various classes of shop practice. The effort here should be not to make the student a skilled workman, but rather to give him such respectful familiarity with the problems of the workshop that he will have a just regard for their possibilities and limitations. He should be so trained that when in his professional work he is brought into contact with the shop foreman, he will be able successfully to coöperate with him.

One or more foreign languages, and drafting, are everywhere recognized as standard requirements of an engineering education and should not be neglected in the course under consideration.

It does not seem to me that any engineering education is complete without a certain amount of knowledge in regard to legal questions, particularly those relating to the legal responsibilities of engineers, to the execution of work under contract, and to the matter of patents. Nothing, of course, should be undertaken at the engineering school in the way of attempting to give to the student such a knowledge as will enable him to dispense with legal advice upon such questions, but he should be provided with sufficient knowledge to enable him to know when to seek legal advice and to be able to lay his case before the lawyers and to give to them all of the facts which are essential to the proper consideration of the question which may have arisen.

While I have laid stress upon the necessity of a preponderance of fundamental studies in the electrical engineering schools and have argued against the tendency to multiply subjects of study by introducing excessive numbers of courses dealing with the details of engineering questions, I do not by any means wish to be understood as desiring to exclude altogether from the studies a goodly number of examples from practice. I would use the examples from practice, however, as illustrating the fundamental

laws and as showing how apparently remote scientific principles are really of the utmost importance in the solution of practical problems.

In choosing the practical examples with which to illustrate a given fundamental principle, care should be taken to select one or more cases from each branch of electrical engineering to which the fundamental principle may apply. In this way the value of the principle will be borne in upon the mind of the student. It will help him to see theory and practice in the proper perspective, and if the examples are well chosen and judiciously placed before the student, they will aid him in deciding upon the particular branch of electrical engineering for which he is best fitted.

At the same time these practical examples, although they may be relatively few in number, will, if adequately treated, not be without some immediate practical value in the student's early professional work.

If the attempt to teach practice is thus restricted, it will, in my judgment, give the desired balance to the theoretical training and go as far as the college should attempt to go in fitting the student for his practical work after graduation.

The Papers Committee have asked me to include in my remarks any criticisms that might occur to me as a result of my experience with technical school graduates. In complying with their request, there are two or three points which I wish to emphasize.

In the first place, many graduates do not seem to appreciate sufficiently that engineering is the determination of the most economical way of accomplishing a desired result. In too many cases they feel that they have done all that is required when they have determined one way of accomplishing a result, and as soon as they have found that way, deem that the question before them is answered.

This state of mind upon the part of a student who has recently graduated and who has never felt the burden of final responsibility is not unnatural, considering the conditions under which his work has been done at college. There, while he may have been taught to look carefully for the most economical solution of a given problem, he could not from the nature of the case be confronted with the severe penalty which falls to a professional man who has failed to obtain the most economical answer to an engineering problem involving large sums of money. The importance, therefore, of earnestly and fairly considering all possible solutions

of the problem in hand should be continually impressed upon the mind of the student.

Many instances have arisen in my experience which lead me to believe that notwithstanding all that is said upon the subject, not a sufficient amount of emphasis is laid upon accuracy. I have often noticed that beginners in engineering seem to feel that an arithmetical error in their work, or an inadvertant making use of one figure when they should have used another, or carelessness in getting together their data, are comparatively trivial mistakes, while the use of incorrect mental processes in endeavoring to attain a result is the only kind of mistake which would be regarded as serious.

Without in any sense condoning the use of incorrect mental processes, I wish to point out that as far as practical results are concerned, errors of the one kind are quite as serious, and render the result of as little value as do errors of the other kind. As a matter of fact, these clerical and arithmetical errors are often more serious in their consequences than errors of logic. Errors of logic can readily be determined by a comparatively brief examination of a subject by a competent chief engineer, whereas errors in computation and clerical errors cannot be discovered without going over in full detail the entire work of the subordinate. No qualities of mind, therefore, however admirable they may be in themselves, are sufficient to compensate for this class of errors which I am now condemning. It would have a very wholesome effect, therefore, in dealing with these errors which are so often condoned in the student's college work, if the instructor would force upon the attention of the student the necessity for accuracy in this respect, and point out to him the unfortunate results upon his future career which such errors would produce if they occurred in his professional work after graduation.

Cases have often come under my observation which show that graduates have too little appreciation of the relations between their theoretical knowledge and practice. They seem to feel that practice is a matter altogether apart from theory, and have no physical conception of what corresponds in nature to their theoretical information. This, no doubt, is in some cases due to a lack of ability on the part of the student to grasp and comprehend his theory, and in such cases the defect cannot be overcome by any amount of training. In too many cases, however, I feel that it is partly or altogether the result of the training which the

student received in the technical school. This defective method of training might be illustrated by a course of laboratory experiments carefully laid out and described in a text-book with which the student is supplied. Specially prepared apparatus might be set up and wired permanently to one or more set switchboards in the laboratory in such a way that the student might, with a minimum of thought and effort, and by following his text-book, which carefully describes the experiment, go through the form of making the tests, carefully entering the results of each test upon printed forms, kindly prepared in advance for him and having upon them a space in which to enter the result of each observation. For a student working under such paternal conditions, it would be well-nigh impossible to fail to make the experiment and record the result of his "laboratory work" correctly. By such a plan as I have outlined the student can complete a course of laboratory practice without having gained the slightest conception of the physical phenomena underlying the experiments which he has made, or of the relations of these physical phenomena to the general laws which he has learned in connection with his theoretical work. While such conditions as I have outlined might seem to represent a state of affairs not existing in any of our technical schools, nevertheless, it is to be feared that in many cases too great an approach to them has been made.

If the few ideas which I have here expressed are understood in the spirit in which they are intended, there will be little danger of my being considered a hostile critic of the engineering school and its graduates. So high is my appreciation of the work of our American engineering schools, and so warm is my regard for their graduates, that I wish to guard against that little danger. This I feel I can best and most briefly do by stating that with rare exceptions the possession of an engineering school training is a requisite for entrance to my own office work, and the net result of my experience with engineering graduates shows that the training which they receive, notwithstanding its imperfections, is of great value to them and to those for whom they work.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

PROPER QUALIFICATIONS OF ELECTRICAL ENGINEERING SCHOOL GRADUATES, FROM THE MANUFACTURER'S STANDPOINT.

BY L. A. OSBORNE.

Any short paper having for its subject the educational needs of a student of engineering must necessarily be limited to the particular requirements to be met. It is therefore proper to state in the beginning that the writer has in mind the requirements of a particular industry and his views are, on that account, influenced by the environment with which he is most familiar.

It is probable that the majority of young men who enter upon a course of engineering in one of our technical schools rarely have expectations of devoting their energies to engineering pure and simple. My experience has shown that the average young engineer rather expects that his preliminary training and education will be of assistance to him in obtaining a foot-hold with the commercial side of industries which are based upon engineering practice. It is not obvious, in seeking for reasons for this attitude, whether our engineering courses are based upon the assumption that the industrial world requires business men with a technical training or whether the supposedly larger emoluments which come to men of affairs rather than to specialists and designers have their effect in diverting the energies of young men after they have departed from the influences which surround them in their academic career, but I believe that the latter form is the determining factor. However that may be, my experience is, that of all the technical graduates who obtain employment with the industry with which I am connected, not more than one in ten is fitted either by temperament or education to take up with success the work of pure engineering.

Temperament undoubtedly has a great deal to do with it, and

the tendency of modern industries to demand technical training of men in its commercial departments undoubtedly has the effect of inviting men to take the technical courses, where, if there were not that incentive, they would have devoted themselves to some other line of activity. There is, therefore, graduated every year a large body of men who are added to the engineering profession but who are not properly fitted to deal with engineering questions broadly.

On the other hand, the authors of the courses which these men have followed have generally not pretended or considered any other probability than that the students are to become engineers pure and simple. There has consequently been turned out a body of men who by inclination are not prepared to follow the so-called drudgery of the profession. At the same time they have been given little instruction or special preparation for the lines of work into which they will obviously drift.

I cannot but believe that before the majority of men have completed a four years' course in college they have given some indication to the faculty of their ultimate tendencies. It seems desirable, therefore, either to differentiate between the different classes of men, with the result that each will be better prepared for the work which it will ultimately be called upon to do in the world, or better still to broaden out the courses in certain particulars to the end that the whole body of engineers will enter upon their work with a fuller comprehension of its duties and its opportunities.

I am quite aware that financial and physical limitations will always prevent anything more than an approximation to an ideal. I know from personal contact with many of our educators that they are fully awake to the growing demands of the profession, and that generally the most earnest efforts are being made to meet these ever-increasing requirements. My remarks should therefore be taken in the spirit in which they are given, that is, not as captious criticism of existing methods, but as an endeavor to point out conditions toward which it might be considered desirable to work.

In considering whether the training of the modern engineer is adapted to the demands which will be made upon him later, we should bear in mind certain latter day tendencies which have largely come about through engineering practice.

There was a time in the history of manufacturing when its activities were directed largely by men who had grown up from

apprentices in the shops and who were primarily machinists and workmen. The work of modern engineering has resulted in the development of enormous industries requiring skill, intelligence, knowledge and a high order of administrative ability, which were entirely unnecessary in the days of small shops and limited organizations. It has followed that the problems incident to this great industrial development have been more than the limited education and intelligence of the old-time shop superintendent could cope with.

The inventions and discoveries which have revolutionized modern industrial practice have been made by comparatively few men. The activities consequent upon these inventions and discoveries require an army of trained men to supervise and direct them. It is in this army that the average engineer can hope to find an outlet for his best talents. I am not now speaking of the few men who, by temperament and by making the best use of the opportunities offered in the technical schools, will ultimately develop into world-recognized engineers, but of that great body of men trained in engineering, who must look to the more general fields for a proper environment in which to exercise their abilities.

In this short paper it is not my intention to do more than to point out suggestive thoughts, hoping that the discussion, which is always more important than the paper itself, will bring forth the opinions of our members on this question, and will do much to aid us in defining our views upon the subject.

Considering the field of manufacturing, it is my experience that not one engineering graduate in a hundred ever looks to that as holding forth anything attractive as a scene of his future labors. Manufacturing to-day in any industry is a proper field for an engineer. It is unnecessary for me to set forth the countless opportunities which any manufacturing concern, be it great or small, offers for the exercise of engineering judgment.

It is true that our technical schools devote a certain portion of their time to "shop work," and endeavor to give to the engineering student a certain facility in the manipulation of tools, both hand and machine; but it is very seldom that the school makes any serious attempt to take up the larger question of the adaptation of tools to special purposes or give instruction in general in the principles which underlie the tool organization of a shop. Consequently, the student's interest is not stimulated, and the majority of the technical school graduates leave college with but very

hazy notions either of the function of tools, the principles of their design, or the machine organization of a shop. In connection with manufacturing, it is also certain that a more thorough knowledge of works organization as applied to the personnel would not only stimulate the interest of the student in this most attractive field, but would be of the greatest importance to his future employers, the industrial concerns throughout the land.

Almost without exception an engineering graduate enters a machine shop in utter ignorance of the principles which should underlie its organization and personnel. It is true that familiarity in these lines comes largely from experience, but it is also true that there are large fundamental facts underlying all successful examples of shop practice and shop organization, the knowledge of which should be of the utmost value to an engineering student.

The man whose work is the supervision of manufacturing processes should also have a competent knowledge of works accounting. Works accounting based upon general accounting practice is a closed book to the average student of engineering. I have been unable to find in the curriculum of any technical school that I have examined any course of study which remotely suggests that this would be desirable knowledge for an engineer. Shop accounting is not a matter for the ordinary expert accountant to deal with. The man who knows the cost of his product—and upon this knowledge success absolutely depends—must apply the fundamental laws of accounting to the particular cases with which he has to deal. There is no more important knowledge required of a works manager than an adequate knowledge of proper accounting methods. In cirticism of this it might be said that ordinary accounting and bookkeeping is a subject which any intelligent man might readily master; but my opinion is that it would be much better for our engineering courses to recognize the important relation which this branch of knowledge has to modern engineering work, and the advantage of including it in the curriculum would lie in bringing the importance of the subject prominently to the student's attention.

All engineers, if they expect, as all do, to achieve prominence in their profession, must sooner or later come in contact with labor. There is no more vital subject facing the industrial world to-day than the relations between employers and labor. Every engineer may hope sooner or later to be an employer of labor. To enable the engineering student to understand the economic laws which govern the relations between employers and labor would add

enormously to his value in a general way. The engineering student to-day has no insight into these questions except as he may gather his opinions through the newspapers or through such desultory reading as he may choose to do. The result is that he is not brought to an appreciation of the enormous influence which this question must have on our future industrial progress. A course which would bring to the students' attention the history of the relations between capital and labor and the economic laws relating thereto would be suggestive and call to his attention vividly its importance, and arouse in him a realization that this is a question which he some day might be called upon to treat intelligently.

On the commercial side, all engineers must come in contact with the problems which introduce questions of business practice. The consulting engineer, the engineering salesman, and the designing engineer will, sooner or later, be called upon to enter, either directly or for his employers and clients, into contractual relations. As it stands to-day the engineering student leaves college with the haziest notions of the principles underlying the law of contracts. Under the circumstances it would seem well if our engineering courses included a short course of law in its relation to contracts.

It may be said that all these things have nothing to do with engineering. This is partly true, but my plea is for engineers with broader horizons. Our technical schools to-day are admirably fitted to turn out men who are well grounded in the fundamentals of engineering. As a rule they are good mathematicians, electricians, chemists and physicists, and have all the technical groundwork necessary for pursuing the profession, but they are, as a class, woefully lacking in comprehension of many of the subjects which are inseparably connected with the practice of the profession.

I believe that much of the manual training, which now occupies such a large proportion of the " actual hours work " in the courses of most technical schools could be replaced with profit by lectures on subjects related to those which have been mentioned in this paper.

No attempt has been made within this short paper to do more than touch upon what have appealed to the writer as the more important and most noticeable qualities lacking in the mental equipment of the average technical graduate with whom he comes in contact.

Discussion.

Professor Goldsborough:—I am not prepared to admit that the practical men always tell us what we want to know, or what they would tell us if they properly appreciated the conditions. The educators of the country have worked hard and have worked well to provide engineering courses that would meet the demands of practical engineering, and they have done it. Because the boys graduate, go out into practical life and do not *fall down*. That is the measure. *They do not fall down.*

Now, to refer to some of the points made—Mr. Gherardi has taken up the matter of telling us what we should give the telephone engineering students to do. During the last few years I have been working on a course for telephone engineers, which is now published in the catalogue of Purdue University. I have talked to almost every engineer of prominence in the Bell Telephone Company. I have talked with almost every prominent telephone engineer in the independent field; I have talked with the managers of telephone plants, with the presidents of the plants, all along during two years. I have conscientiously gone among them, and the course that we give you *is what they said they wanted*, and nothing else. It is being administered by a practical man; a man who was taken right out of the field; and some of the telephone people are mighty anxious lest he tell those students something that they do not want them to know.

Now, Mr. Gherardi has told us what we should give the men in telephone engineering; that they should have all that electrical engineers now have, and then that they should have a whole lot more besides. And he has not told us where the time for all that is coming from. He has not told us that the young men of this country who are growing up and who are going to be the bone and sinew of the engineering profession, are young men without financial means. They are not the fellows who have been brought up in rich families. They come right out of the backwoods and they have no advantages. But they persevere, they materialize, and they are put in charge of the most important work of these big companies.

Now, as to the best training for a business man. It is not the literary training. The best training, in my judgment, that exists to-day for a business man is the engineering training, because it comes more nearly up to the standard of meeting commercial requirements. We should have in a few years a good course which will teach commercial business engineering. I say "business engineering" for the reason that all of the great work of the future is going to be very largely engineering of one kind or another.

Professor Jacoby:—It may be of interest to some of the practicing engineers, if they have not followed closely the recent developments in our courses of instruction, that in several of our institutions of learning courses of study are suggested, by which the student may obtain the college

course and the engineering course in six years, by properly electing the work in physics, chemistry, geology and other subjects in such a way that when he gets his degree of A.B. at the end of four years, he will also have completed two years of the engineering course.

PROFESSOR A. F. GANZ:—I feel it my duty to say in reply to Mr. Osborne's paper that at the Stevens Institute of Technology during the past year a Department of Business Engineering was inaugurated. Two lectures a week were given by President Humphreys to the seniors on matters of shop accounting, depreciation, statistics, laws of contracts and general business methods. The value of this business training is well recognized at the Stevens Institute and we would like to give more of it but lack the time. Our curriculum is full. Every available hour is taken, and we are doing all that we can do.

In reply to Mr. White's paper and the suggestion that English could be taught to good advantage by requiring reports on laboratory and other work, I would like to say that to make these reports valuable, it is necessary that they should be very carefully corrected by the instructors, both for technical matter and for English, handed back, rewritten by the student, handed in again, and this process continued if necessary until the report is satisfactory in every respect. Unless this is done the work of writing reports is of little value as an exercise in English. We are doing some of this work and hope to do more, but, as I said before, the time is limited.

Another part of our course which brings the students into close contact with practical matters is making inspection trips to power plants and shops where they see how work is done. In addition to numerous short trips to take our senior students every year on a ten days' trip, visiting such places as the Westinghouse and the General Electric Works, various railroad and machine shops and power plants. We come here to Niagara to see the electrical developments. To make these trips of the greatest value it is necessary in my opinion to give lectures before each trip, illustrated with lantern slides, so that for example when a student sees a particular generator in a power house he knows how it is constructed and when he goes down a wheel pit and sees the casing of a turbine he knows how that particular turbine is constructed. I think that this kind of work is very important and together with the work in the laboratories brings the student as close to practice as we can hope to do in a technical school.

PROFESSOR CALDWELL:—I very greatly appreciate these papers by practical men upon the question of engineering education. For the most part I do not think that the views expressed differ very widely from those held by engineering professors, but they are certainly of great value to us for use with our students as evidence of the needs of the practical man.

The student is very apt to take the view that the details are

the all-important thing, and he is inclined to feel that he is being defrauded if he gets a large amount of this more general training, and to be able to point to these papers as evidence of the importance of that class of work is very valuable. I wish, however, to insist that the great difficulty that presents itself to the engineering professor is not what things would be desirable in the course, but what things should be left out of the course in order to get these other desirable things in. I wish that practical engineers who give us such papers as this would give us some views on that subject. It does very little good to tell us that it would be desirable to have all these additional subjects. We already know most of that ourselves. But we do not know what to leave out or what to condense in order to put these subjects in. We do not feel that the practical engineer would be satisfied, to have us leave out anything that we are giving now. To be sure, the subject of manual training has been mentioned, and it has been suggested that that might be cut down. In some institutions that may be so, but in many of the engineering schools at present the manual training in shop work is reduced to what seems to be a minimum, just enough so that the students will have an idea of the use of tools and how they are to be applied in carrying on engineering work.

MR. HUGO DIEMER:—I wish to confine my few remarks to Mr. Osborne's paper only. It has for some years seemed to me that we needed in the shop work in our schools an opportunity for giving the students more in the way of a careful study of sequences of operations, of cuts, of speeds and of the best adaptation of tools to specific work. It seems to me that the introduction of this work is so important that it should be taught, even if it required the laying out of a smaller number of distinct shop exercises. Another point, in my own experience in teaching machine design to mechanical engineers, I have required the students to prepare a complete bill of material of the parts, together with an estimate of weight and cost of material, and a discussion of the details of tools and processes required in turning out the design. With regard to the question of shop accounting and questions having to do with methods of compensating labor, I believe that at the present day the mechanical engineering departments of several of our leading institutions offer courses in this work, calling them sometimes by the name of "factory organization," sometimes "factory systems," sometimes "shop economics." I have for several years given a term's course in this work, covering five hours per week, which involves considerable collateral reading of current engineering literature by the students. It seems very desirable that students in electrical engineering should also join in such classes since so large a number of the men, according to Mr. Osborne, will be engaged in the manufacturing branch of the electrical field. This fact is too often not realized by the students themselves. We all know that a student, upon graduation, seems very much disappointed

if he doesn't get immediately into the field of testing or designing.

Both instructors and students have failed to give due attention to the constructive branch of engineering, and to the principles and methods essential to the most successful execution of the work. It is fortunate that the importance of this branch is emphasized by a man in Mr. Osborne's position, who is both electrical engineer and manufacturer.

I would also advocate in addition to the methods already suggested, that students be given practical experience in the use of representative methods of factory accounting and management in the school shops. I have suggested before the Society for Promotion of Engineering Education in a paper on "Education for Factory Management" that certain of the upper classmen act as foremen and also as accountants and critics of the work, following methods of organization employed in best commercial practice. It may be true that this would be "playing at manufacturing" as it was called by a member commenting on my proposition. It is equally true, however, that all of our engineering instruction may be just as fairly called "playing at engineering."

PROFESSOR ALLEN:—I do not feel, as I think Professor Goldsborough may, that those papers are unfair or that they attack the engineering professor. If I understand it, these gentlemen were asked to present their views as to what is desirable in an engineering graduate. I do not understand that they were asked or that they attempted to state what should be put into the courses. They state what is desirable, for our consideration, and with the hope and expectation that teachers of engineering will take to heart everything that they say, and so far as possible, bring about the results that to them seem desirable. I should like to state what I think is the problem of the educator with relation to the student. It is impossible that our engineering schools should make a finished engineer. There is not time for that. An engineering college does not have the facilities or the opportunities for doing all that is necessary to make the successful engineer. I have in mind the element of experience. There is left, then, for the college the obligation to provide the student with the proper theory, and to that work the college must be devoted at all hazards. But proper theory cannot be given unless it is united with applications, or what you may call experience, and the college graduate does, as a matter of necessity, if he acquires proper theoretical knowledge, acquire quite a little of experience in that way. I believe, in providing the element of experience; that is, so much as is necessary to give point to theory; and so much as is necessary to put the student graduate in the way of gathering the larger experience which shall make him a complete and valuable engineer.

The manufacturer, I am inclined to believe, is oftentimes disposed to expect too much of the schools. If there are the two things mentioned to be done for the engineer, who shall do each

part of the work? The school will do only a part. It cannot do all. The manufacturer with the physical material he uses, expects to receive it in a certain condition, and to put additional work on it before he allows it to depart from his works. I believe that there is another burden on the manufacturer. Part of his outfit is the young engineer. I believe he should put some work on the young engineer.

The matter of accounting has been given as much attention as any other single subject of discussion in the proceedings of our Society for the Promotion of Engineering Education. That an understanding of accounting is valuable and necessary for the successful administration of manufacturing enterprises goes without saying; but where shall the work of training in this direction be done? Are there facilities existing in the school of engineering to take up that work to the best advantage? Should not the manufacturer consider it a part of his duty to take the engineering graduate who is turned over to him and to educate him in matters of that kind, in the regular manufactory, which is a laboratory of accounts, if you please, where the work can be done better than it can in the college of engineering? Without feeling at all positive on that point, my impression is that that is part of the work that the manufacturer should expect to do in producing the engineer whom he wishes to use. The school and the manufacturer should each do the part of the work that it is best capable of doing.

PROFESSOR WALDO:—With Mr. White's permission, I would like to ask him why he retains Latin in his ideal course of study for the engineer?

MR. WHITE:—I think that most of the papers have shown that those of us who have gone into professional life appreciate that the great problem, perhaps, for the educator to solve is how to do ten years' work in four years, and how he can condense into the limited time available a fair general training in "learning how to learn" and some specific knowledge of particular subjects. As to the suggestions made, I would not presume to dictate, or even to suggest specifically, to the educator. I thought it would do no harm, however, to indicate in a general way some subjects which might advantageously have preference over some others, which are also important, but, from our point of view, relatively less important. Latin was not included among those which are considered of primary importance, but it should be in the secondary or perhaps in the tertiary list. It seems to me that students should decide on the amount of time available. If they can take only studies of primary importance, it would perhaps be better to omit entirely those in the secondary and tertiary lists. In such cases it would possibly be best to omit entirely Latin and French and to concentrate the time on some of the more important studies—mathematics, physics, mechanics, chemistry, and fundamental engineering subjects.

PROFESSOR GOLDSBOROUGH:—I want to say that I do

not feel that one word of criticism of our teachers has been voiced in any one of the three papers, and if my remarks led any one to think that I have that opinion, I wish now to say pointedly that such is not the case. *Now, if the practical men will tell us about the course that they put men through after they graduate, what is demanded of them and the order in which it is demanded, and of the attitude that we should teach the student to hold toward his future engineering work,* THEN THEY WILL BE GIVING US SOMETHING THAT WE VERY MUCH WANT TO KNOW. Mr. White's paper gives us a great deal more of this kind of information than any of the others. It is of value in showing teachers the ends for which they must develop their students.

PROFESSOR H. S. CARHART:—I should like to call attention briefly to another phase of engineering education which has not been alluded to directly. It seems to me that there is no necessity for having a differentiation in engineering training in the schools—the differentiation should come in practice, after the man is through with the technical schools. And I have a few times made a suggestion privately which I am going to repeat, and which has met with considerable favor from engineers. It is evident that more time is needed for the training of the engineer. It has been my practice in the little work that I have done in engineering education, to insist upon it that we should teach principles, with enough of the laboratory or the shop, as has been said, to give point to those principles, to connect them with real practical affairs, and not to let the laboratory or the shop encroach upon the valuable time of the student further than this; and I have been greatly gratified when our students have returned, after one or more years' experience outside, to have them say of their own accord that this plan is right, that they can get more experience in practical affairs in six weeks in a large manufacturing establishment than they could get in college in four years. The point I wish to make is this, that instead of trying to make a complete mechanical, civil, electrical, marine, telegraph, telephone or any other sort of engineer in a training school, we should arrange the course if possible so as to make *an engineer.* (Applause.) Let him apply the adjective after he gets into his practical experience. In other words, it seems to me that it should be the effort to lay a broad foundation in those subjects which the engineer must have to build upon. Now, as you are perfectly well aware, a man graduates as a mechanical engineer and goes out and practices electrical engineering; graduates as a civil engineer, or in the civil engineering course, and goes out and practices electrical engineering; and so on around the whole series. In other words, it is almost never possible to tell during a man's college course in what field he is going to work when he gets through. So that if we could return to the old practice of dividing engineering into two classes, which used to be military and civil engineering, as you are well aware, make engineers of one or the other of those

divisions, and have a five year course in which to do it, under the high pressure which seems to be coming into vogue now for all sorts of transmission of energy, possibly we could put into the course what would satisfy everybody.

MR. RUSHMORE:—My remarks are from the standpoint of a man in an engineering office who has had to examine many possibilities to obtain assistance in the performance of such work.

College courses should tend to develop character as well as intellect. Men should have initiative, originality, self-reliance, observation and above all, accuracy.

The amount of information which a graduate possesses is not of great importance in comparison with an ability to obtain it quickly. Principles should be taught thoroughly. Enough applications come later.

It would express my idea that a college education should not be taken as complete in itself but as the foundation for what comes afterwards.

PROFESSOR WILLIAM KENT:—The criticism made by Mr. Osborne is the same that we have heard for the last 25 years; that is, a criticism of the college graduate because he doesn't know enough. There are two kinds of college graduates: First, the one who is just freshly out of college and who does not know a great deal, and secondly, the man who has taken a post-graduate course in the works "in overalls and grease," as I believe the expression is. I do not think the criticisms Mr. Osborne makes will hold as to the second class of graduates; those who have taken five years' shop experience after graduation and have specialized in telephony, business, engineering accounting or some other branch. I do not believe that these criticisms apply to that kind of graduates. Now, the requirements for an engineer, not an engineering student, but an engineer, which are laid down in Mr. Osborne's paper, are the qualifications of a man not less than 40 years of age, with an experience of at least 15 years after he is graduated.

PRESIDENT SCOTT:—Mr. Osborne will not have attained that age himself for four or five years.

PROFESSOR KENT:—Well, he is asking for more than he has himself then, in these graduates. We must not expect too much from these immature minds, the recent college graduates. What the student gets in the college course is the mental training which prepares him to begin this post-graduate course "in overalls and grease," and the two courses will finally lead to what Mr. Osborne wants.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

THE TYPICAL COLLEGE COURSES DEALING WITH THE PROFESSIONAL AND THEORETICAL PHASES OF ELECTRICAL ENGINEERING.

BY DUGALD C. JACKSON.

At the Chicago meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS held eleven years ago, I presented a paper relating to the subject now under discussion. The proposed subject then apparently created some consternation amongst the members of the committee on papers, who seemed to fear that it was not of sufficient interest to the Society. The old prejudice still held against " college men " in the minds of so-called " practical men," who had grown influential in engineering practice without having had experience of college life and training. Happily, the foundation for this prejudice has ere this been destroyed through the influence of the industrial results achieved by college men. The old prejudice, so far as it now exists, has more particularly drifted into the way of criticism of the engineering schools rather than of their graduates, and the character of the schools and the training they afford are subjects of eager discussion in engineering circules.

This extended interest now manifested in the work of the engineering schools produces a situation which may be of great usefulness to the schools. The character of a college may be that which its alumni determines, and any engineering school may be improved by thoughtful suggestions and broadly considered criticisms emanating from its alumni and others who have its best interests at heart.

Two fundamental propositions must be held clearly in view in

all such criticisms, if they are to be of service to the educational administration of the engineering colleges:

1. That it is the business of these colleges to train young men into fertile and exact thinkers guided by common sense, with a profound knowledge of natural laws and the means for utilizing natural forces for the advantage of man. In other words—it is the business of the engineering colleges to produce, not finished engineers, but young men with *a great capacity for becoming engineers*, the goal being obtained by the graduate only after years of development in the school of life.

2. The problem to be met by the engineering colleges is more particularly a problem in "how to properly train" to the stated purpose. The names attached to the subjects taught are not so important as the results produced by the teaching; namely, the effect impressed on the student's powers. This is a teacher's problem: a question of pedagogy, rather than of the engineering profession. It must be met with all the directness and power of the engineer's best efforts, but it cannot be solved as solely relating to the engineering profession. Much error on this point lies in the minds of many who assume the part of critics of the curricula of the engineering schools.

In this connection I may be permitted to point out that proposals set up as apparently new in the presidential address one year ago, by President Steinmetz of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, have for many years been largely included within the ideals of numerous American colleges of engineering. It must be admitted that only few of the engineering schools are living up to their ideals. This is partially due, on the one hand, to personal or institutional ambitions which father the sensational or spectacular and thereby inevitably ruin good teaching, and on the other hand, to the meagre support both in encouragement and funds which I have noticed is the lot of the engineering schools attached to many universities. The latter, like the former, is often the result of personal prejudices or ambitions.

Most of the faults which are so trenchantly and indiscriminately charged to engineering colleges by many engineers, should, so far as they are real, be laid to the pedagogical inexperience and faulty ambitions of the authorities of the many colleges, in which it is safe to say that the ideals are high and well centered and the administrative organizations hold the ideals continuously in view.

The query here naturally arises: "Of what do these ideals

properly consist and how fairly should they be met by the college before its course in electrical engineering may be approved as of first rank?" Electrical engineering demands industrial engineers —men with an industrial training of the highest type, competent to conceive, organize and direct extended industrial enterprises of broadly varied character. For the highest success, these men must be keen, straightforward thinkers who see things as they are and are not to be misled by fancies; they must have an extended, and even profound knowledge of natural laws (more particularly of those relating to energy which rest on the law of conservation of energy), an extended knowledge of the useful applications of these laws, and an instinctive capacity for reasoning straight from cause to effect. Moreover, they must know men and the affairs of men—which is sociology; and they must be acquainted with business methods and the affairs of the business world. Briefly, to reach his highest influence, each man must combine in one, a man in the physical sciences, a man in sociology and a man of business. All engineers cannot reach this high mark, but the engineering college course should start each of its students toward that degree of attainment which his individual powers will permit.

Michael Faraday (whose conservatism and intellectual clearness are proverbial) said that it requires twenty years to " make a man " in the physical sciences. The engineering school must put each student in the way of becoming, so far as his mental and physical powers warrant, not only a man in the physical sciences, but a man in sociology and a man in business as well; and this must be done within the narrow limits of four years. It is clear that only the foundations of " the man " may be laid in the prescribed time, and the engineering college must, therefore, rigorously hold itself to the fundamentals. The engineering college faculty which is contented to deal out so-called " information courses " on the narrowly empirical side of engineering practice, deals a wrong to its students which they may not recognize at the moment but which will ultimately tell heavily against their success.

The students that enter the engineering schools of the West, and I presume likewise of the East, are from amongst the most vigorous minds of the high schools and the preparatory schools; and yet it must be admitted that they ordinarily possess little power of clear thinking, power of initiative, regard for accuracy, or understanding of continuous and severe intellectual effort, as

these important attributes are understood in industrial circles. They are not yet mature in body and are less mature in mind (the latter being, I think, in accord with the natural order of development.) But they are commonly well equipped with physical vigor and latent mental strength. Their preparatory schooling has given them a defective acquaintance with the construction of the English language and the spelling of English words, a still more defective acquaintance with French or German or a fairly good grounding in elementary Latin, a smattering of civics and history, a training in the elementary principles of arithmetic, geometry and algebra, from which the factor of accuracy in application has often been omitted, and perhaps an enthusiastic interest in the physical sciences.

This enumeration of the attainments of the students entering the engineering colleges may perhaps be interpreted as reflecting on the secondary school teachers, but I wish vigorously to deny the validity of any such interpretation. I can truthfully say that, considering all of the conditions, there is no more painstaking and right-wishing body of people than these teachers.

Many of the faults in the preparatory training of our engineering college students are caused by a doubt, which is now apparently agitating educational circles, whether the high schools shall be the " people's colleges " or remain in the station of secondary or " preparatory " schools. This doubt is apparently not yet resolved in the minds of the moulders of educational thought; but the traditional old time secondary school training which produced men who could spell and cipher and who had received a thorough and accurate drill in the details of one language, is certainly to be preferred as a preparation for an engineering college course. In my own estimation, when accompanied with history and a year spent in civics and natural science, it is to be preferred not only as a course for preparing the student for college but also as a school course for those numerous students who cannot go through college.

Taking the students as they come and may be expected to come for the present, the electrical engineering course must include the following branches of learning which are preparatory to the more strictly professional studies:

1. That fuller training in the construction of the English language which is requisite to clear thinking and clear writing, preferably accompanied by an additional language for added strength.

2. The collateral part of expression in drawing.

3. Mathematics through an appropriate amount of calculus including the integration and solution of equations involving derivatives, and instruction in the use of co-planar vectors, and, perhaps, quaternion quantities, all of which should be taught as applied logic with special emphasis laid on interpreting the meaning of equations.

4. The science of chemistry, soundly taught.

5. The science of physics soundly taught, with particular emphasis laid on the elementary mechanics.

6. Applied mechanics.

Mechanics—the philosophy of matter, force and energy—is the backbone of the electrical engineer's college training.

Instruction in the science branches should be accompanied by well conceived and properly conducted laboratory work, mostly of quantitative character, accompanying and illustrating the class room instruction; and all instruction, whether in natural science, mathematics or languages, should be under the direction of men who are engineers or in full sympathy with the aims and ideals of engineering.

A limited amount of manual training may well accompany these studies; and likewise, if time can be found for it without overburdening the physical powers of the student, a limited amount of proper instruction in surveying (including the use of the compass, transit and level) will always prove a force for quickening his perceptions, and, at the same time, will put him into *possession of knowledge* of probable future value.

In a few of our engineering colleges which rigidly demand the best preparatory work from the high schools, and which are, at the same time, best manned in their faculties, not less than two years are required to cover the ground above described, if the work be done in a reasonably satisfactory manner. But the above ground cannot be covered with anything like success in *much less* than three years, in the larger number of engineering schools that are usually accorded high rank.

After covering these branches, it seems to be the tendency in many colleges to fly off into superficial or descriptive courses relating to engineering practice, during the remaining time of the allotted four years. This is especially apparent in those colleges where the faculties are ambitious to see their graduates take an *immediate* place of considerable responsibility in the world. This is a fault that destroys much of the ultimate advantage

which the students may derive from their engineering course. It is a fault, also, which casts just suspicion on engineering education alike in conservative academic circles and in well informed industrial circles.

A resort to mainly descriptive courses of instruction during the latter portion of the student's life in college, largely neutralizes the advantage flowing from the instruction in the fundamentals heretofore described. The students are yet to be taught many things relating to engineering life. They must learn something of the forms and formalities entering into business affairs. They must learn the characteristics and uses of materials, their correct application to the building of actual structures, the meaning of kinematics, and the processes of designing and using real machinery. They must also learn to reason regarding the special principles of hydraulics and thermodynamics, the way in which such principles enter into the design, construction and operation of machines, and the manner in which they *modify* the usefulness of machines and the efficiencies of numerous industrial enterprises. Again, they must learn to reason clearly and rationally in regard to the specific principles relating to applied electricity, including its widely diverse factors, and in regard to the way in which these principles enter into every day practice. Further, they should learn something of the history of the development of engineering as well as of the lives of its great men, for the stirring of proper ambitions.

The electrical engineering department should be divided into not less than four subdivisions, comprising respectively: Applied electromagnetism, which includes the principles relating to electromagnetic machinery and apparatus; the theory and practice relating to all those numerous phenomena which accompany variable current flow; applied electrochemistry and electrometallurgy; and electrical installations, which subdivision includes the application in engineering practice of the numerous principles to the design, construction, operation and testing of complete installations and the component parts thereof.

The teaching force of the department should afford a competent expert engineer for the head of each of these subdivisions, and such additional well trained force as may be necessary adequately to carry on class room and laboratory instruction for undergraduate and advanced students who attend the college. The head of such a department should spend much of his time in supervising the teaching in class-room and laboratory, which is performed by his various subordinates.

But through all of this professional instruction of the latter part of the course, it is still *principles*, *principles*, *principles*, and rational methods of reasoning which must be taught, if full justice is done the students, until each student becomes a man of open mind, keen observation, analytical thinking, and accurate powers of inference. This instruction should be kept close to the tenets of good practice and the senses of the student should be constantly stimulated by illustrations and problems drawn from practice. The drill in reasoning can undoubtedly be best gained through rational instruction in the useful applications of scientific principles and laws; and no criticism can be justly passed, even by the most conservative educational circles, because the graduate is enabled to earn his living as a result of this training. But the purely descriptive should be avoided except in a few cases where it has a specific function in improving the understanding of an application of principles or is adopted as a desirable auxiliary to stimulate the sustained interest of the students and thus add vitality to the teaching. Indeed, except for the purposes here defined, the introduction of the purely descriptive into the electrical engineering course, wastes the students' time and injures their training, thus impairs their prospects of ultimate breadth and power.

The typical courses in electrical engineering which are to-day advertised in college catalogues belong to three classes or combinations thereof. Only the third of these may be acknowledged fairly to meet the proper ideals in such a course. It is to be remembered that I speak of professional engineering. No one possesses a fuller sympathy with the ideals of schools for training men for the mechanical trades short of engineering and bordering thereon, but these schools are not considered in my present discussion.

First are courses in which predominate the old time instruction in physics, which has far more to do with the illustration of the beauties of nature than with the great underlying natural laws. The teaching of mathematics, mechanics and like ground work studies is not ordinarily well supervised in colleges that maintain such courses in electrical engineering; because the administrative authorities are out of touch with the industrial world, and mistakenly put the superficial and spectacular in science into the place of that sound instruction through which only an engineering course may be rightly maintained. It is needless to add that the average graduate from courses of this type is ordinarily of

less value in engineering than the average graduate from an old time classical course where at least thoroughness is a requirement; and electrical engineering courses of this type are rapidly disappearing through a merging into one of the following types.

Second, are courses *in which* the ground work studies (English, mathematics, chemistry, physics, mechanics) are perhaps reasonably well taught through the earlier years, but in which the latter part of the course is diverted to the training of inexperienced students for immediate " jobs " where the students may find some responsibility and proportionate pay immediately after graduation. These courses do not teach engineering in the sound sense. " They are likely to prove injurious to promising students," by occupying time in teaching them handicrafts in college which they could better learn in the factory or field, or in teaching empirical methods of practice which change almost before they can be put to useful account by the graduates.

The students in these courses frequently gain the impression that the highest type of engineering practice is no more than an advanced artisanship and that a graduate from the electrical engineering course is the equivalent of a journeyman. The most serious injury flows from this, through the undesirable narrowing of ideals and ambitions. This unfortunate result occurs the more readily because the popular usage of the word engineer makes it denote either an engine driver (a man of purely manual calling) or a man skilled in the principles and practice of engineering.

Third, are courses following the ideals which I have herein earlier described. Incompetent students who enter these courses are soon discouraged and drop out. Those whose calling is to artisanship go elsewhere either to a different school or directly to an apprenticeship. Those who complete the course, as a rule, are competent men; but they are not likely to enter immediately into positions of much responsibility, but rather to go into the so-called " cadet " positions or " student " positions of great industrial enterprises for the purpose of gaining that experience in the crafts which may enable them to make the most extended use of their training in principles. Here they gradually " find themselves " and ultimately reach the influence in the industrial world for which their calibre and training fits them. These men, if properly taught, have clean cut ambitions and high ideals as well as the ability to think well and do wisely. Their earnings, and perhaps their usefulness to their employers, may

be not so great for a short interval as those of the men who are taught more of empiricism and artisanship and less of rational science during their college course, but the advantage soon flows in a strong current towards the scientifically trained.

The men who are responsible for this third type of electrical engineering courses may reasonably cry to be delivered from judgment upon the success of their work which is based on the average earnings of the graduates during their first year out of college. The medical schools and law schools are judged by the attainments of their graduates reached in a decade or even in a quarter of a century, and this also should be the basis upon which to judge the work of the electrical engineering courses of this third and highest type.

Do not believe for a moment, however, that I would teach all theory and no practice. The earlier parts of this paper prove the contrary. In truth, right theory and the best practice are one, and practice which is out of accord with right theory is mere rule of thumb and can be bettered. The best college course in electrical engineering is the one which so teaches the fundamentals that right theory may be fully grasped, and which constantly illustrates the bearing of theory by examples derived from good practice. The administration of such a course requires thoughtful, clear-headed men, who are acquainted with the principles and right practice of pedagogy as well as trained in the principles and experienced in the practice of engineering.

My discussion of the subject makes it clear that there is a wide variance between the methods of the colleges which support electrical engineering courses. Complete unity is not only impossible but would undoubtedly be undesirable, since scope for individuality is as essential here as in the control of industrial enterprises; but the cause of sound college training for electrical engineers would be advanced by any action which clearly placed the true aims of the college courses in electrical engineering before the authorities of all of our colleges which support such courses.

PROFESSOR JACKSON:—I may add that many of the greatest weaknesses of electrical engineering courses are due to the fact that the executive heads of colleges or universities do not always understand what engineering truly stands for, and they often have no fair conception of the soundness of training that is required for its practice.

PRESIDENT SCOTT:—I think it best to have the next paper now, by Mr. Johnston, "Engineering English."

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

ENGINEERING ENGLISH.

BY T. J. JOHNSTON.

This paper is a corollary of the discussion at Great Barrington last summer, and refers to only one subject which should be included in the curriculum of an engineering education; that is, the English language.

It should be self-evident that the first preparation of the engineer for his profession is to acquire a knowledge of his vernacular, the "first tool of the mind." It has been well said that one who thinks clearly can speak clearly; in fact, we cannot know that the man's thought is clear until he expresses it so that we, having regard to our own limitations, can understand it. That this is true will be borne in upon anyone who is required to consult engineers about what has happened at particular dates. Everyone knows the difficulty of proving precisely the events of the long ago; but here I do not refer to the fallibility of the memory, but to the mere expression of ideas. It is a common thing that no two engineers describing the same phenomenon will give anything like the same description, and this is due not to their want of knowledge of the phenomenon, but to the inaccuracy of their language. That I am not alone in this view is evident from the expressions of competent authorities; I may instance an article of Prof. H. W. Wiley in *Science* for November 28, 1902, page 845, where he says:

"I have often been mortified at the English composition of college and even university graduates. Men who have attained eminence in particular branches of study often seem incapable of expressing their thoughts in any proper way. Their English is

inexact, clumsy and inconsequent. Clear expression seems to me to be the legitimate outcome of clear thinking, and the neglect of those early studies which enable one to express himself clearly and forcibly is a fault which can only be remedied by long years of mortification and hard labor."

I also cite the address of Prof. John Perry, to which Mr. Mailloux referred in the Great Barrington discussion.

"Only one subject—Latin—is really educational in our schools. I do not mean that the average boy reads any Latin author after he leaves school, or knows any Latin at all ten years after he leaves school. I do not mean that his Latin helps him even slightly in learning any modern language, for he is always found to be ludicrously ignorant of French or German, even after an elaborate course of instruction in these languages. I do not mean that his Latin helps him in studying English, for he can hardly write a sentence without error. I do not mean that it makes him fond of literature, for of ancient literature or history he never has any knowledge except that Cæsar wrote a book for the third form, and on English literature his mind is a blank. * *

"I ask for a return to simplicity of system. English (the King's English; I exclude Johnsonese) is probably the richest, the most complex language, the one most worthy of philologic study; English literature is certainly more valuable than any ancient or modern literature of any one other country, yet admiration for it among learned Englishmen is wonderfully mixed with patronage and even contempt."

"Well-equipped schools of applied science are getting to be numerous, but I am sorry to say that only a few of the men who leave them every year are really likely to become good engineers. The most important reason for this is that the students who enter them come usually from the public schools; they cannot write English; they know nothing of English subjects; they do not care to read anything except the sporting news in the daily papers; they cannot compute; they know nothing of natural science; in fact, they are quite deficient in that kind of general education which every man ought to have."

I do not mean by this criticism that engineers should spend long periods in learning the grammatical and rhetorical construction of the language; but I do mean that English composition should be kept up in engineering schools and that engineers should be drilled in the use of English until they can express with entire accuracy the meanings which they so often

commit to formulæ. Pick up any engineering article, and one may rarely read a page without some blunder appearing which spoils the sense either by not saying what the engineer means or by saying what he does not mean.

"Have something to say, and say it," was the Duke of Wellington's theory of style; Huxley's was "to say that which has to be said in such language that you can stand cross-examination on each word." This is the secret of his lucidity.

To show how far from the criteria of style of either the "Iron Duke" or Mr. Huxley our engineers are, I quote a few examples of engineering English.

"Generator dissembled."

"More customers, cheaper the cost of production."

"Formerly the slag of steel works was considered purely a dead waste, but some few years ago its valuable fertilizing value was discovered, and now this formerly valueless waste is one of the world's most valued fertilizers."

"Such schemes as M. ————'s is not a solution."

"A body like you propose."

Of certain generators, it was said they "can not be run in parallel."

"This operation is to be operated at every station."

"In a shaft 8,000 feet deep the cost of *cooling the temperature* would be considerable."

"How much we have had to pay because of the slow speed."

"Details as to *how small* turbines could be manufactured."

"Encourages attack upon the doctrine of the right * * * to control their business * * * ."

"This discharge took place perfectly regular."

"There is no reversing plugs."

"For which the unenviable distinction of being the worst in the world is often claimed for it."

"To this was added two * * * generators."

"Gas engine would develop along the same lines as the steam engine had done."

"The low height of the turbine permitted a reduction of the height of the engine room."

"The correctness of my conclusions have been amply demonstrated."

"This can be done equally as well with the motor at no load as at full load."

"Four motors * * will perform a faster schedule."

"An almost infinitestimable amount."

"The last two thirds" (of a commutator brush).

"The matter of convenience * * is shown in every detail."

"Brackets cast solidly with frame."

"The rings * * * are circular in shape."

"One and the same motor."

"The car is well lit."

"Not only securing pole (pole-piece) but also of drawing same down to the tightest of magnetic contacts."

"The cost of superimposing a second floor on the present system would cost as much as the original cost of building the present system."

"The company find it impossible to buy only at retail prices."

"Which renders great economy and rapid construction."

"The three top voltages were the * * * ones * * * used."

"Trains can run at fast speed."

"The hollow of both electrodes communicate with the open air, and when in contact form an air-tight joint.

"Their errors" (of electrical measuring instruments), "were determined by taking them to the works of the Weston Co."

"Continued to do good work when pronounced as ruined."

"We do not think present conditions demand."

"A fewer number will perform a given amount of work four times as long as any other cell of equal size."

"There is no question but that."

"It would have been better to have had"

"Why does a cell constant change when the density of the solutions change?"

"The lapse of time which are here chiefly in question."

"Not yet fully decisive."

"The correct solution for the problem of cause has been discovered."

These (about five per cent. of those I have seen) have been gleaned since the Great Barrington discussion, from reports of engineers, descriptions of operations furnished to engineering periodicals by engineers in charge, and, "'woe is me," from letters to the technical press written by professors of applied physics in universities! I regret to say that some of the most glaring solecisms are from the last named source.

Wendell Phillips once said that there are only thirty-seven jokes in all languages, but Mr. Phillips died before electrical engineers had written much.

It is only necessary to refer briefly to the inaccurate use of terms common in the profession, and particularly to double meanings applied to well-known words which should be terms of precision. "Static transformer," when stationary transformer is meant; the "capacity" of a system, when the maximum output is meant; the "field" of a generator, when the field-magnet is meant, are common examples of the appropriation of a well-known term to a new use, generally inaccurate. "The time would fail me" to do more than shake hands with our old enemies. "Equally as well," "the two highest," "one and the same," *et id omne genus*.

I see many mining engineers in the course of the year. Respectable vagrants as they are, their correct and often elegant diction is a surprise and a pleasure, and somewhat of a reproach to our own members; though a mining engineer, to be sure, would have but a dry practice if he could not furnish the materials for a good prospectus.

This is no protest against the study of languages other than English. *Per contra*, just as no man can be a sound mathematician who confines his study to algebra or trigonometry, so no man can learn English thoroughly without some comprehension of its sources in other languages. The true meaning of a word can only be learned by learning its root, and from that its trunks and branches are easily understood.

Let no man say "I am too old to take up such studies; they were neglected in my youth, and I am as I am." Caleb Cushing, Attorney General of the United States, statesman, diplomat and jurist, learned in literature and science, began the study of French when he was seventy years of age. The subsequent proceedings are not generally referred to; but having heard Mr. Cushing's French, I may add that although public safety prohibited his pronunciation, his knowledge of the shades of meaning of the spoken language would have shamed many English-speaking persons long resident in France.

Most of the errors in Engineering English are due to want of attention; few engineers revise the language of their reports and articles as they do the tables and formulæ upon which the text is based; fewer still, even in important investigations, think it worth while to have the text read by another to detect errors.

I may quote from President Woodrow Wilson's inaugural his unanswerable plea for a liberal education, as a special plea for adequate instruction in English, either as a preparation for, or better still, for both that and a part of an engineering course.

" No doubt the old, purely literary training made too much of the development of mere taste, mere delicacy of perception, but our modern training makes too little. We pity the young child who, ere its physical life has come to maturity, is put to some task which will dwarf and narrow it into a mere mechanic tool. We know that it needs first its free years in the sunlight and fresh air, its irresponsible youth. And yet we do not hesitate to deny to the young mind its irresponsible years of mere development in the free air of general studies."

" What we seek in education is a full liberation of the faculties, and the man who has not some surplus of thought and energy to expend outside the narrow circle of his own task and interest is a dwarfed, uneducated man. We judge the range and excellence of every man's abilities by their play outside the task by which he earns his livelihood. Does he merely work, or does he also look abroad and plan? Does he, at least, enlarge the thing he handles? No task, rightly done, is truly private. It is part of the world's work."

" A merely literary education, got out of books and old literature, is a poor thing enough if the teacher stick at grammatical and syntactical drill."

" It is not the education that concentrates that is to be dreaded, but the education that narrows—that is narrow from the first."

Do we not all assume too readily that because we speak, or think we speak, English, our expression of the thought in our minds is impeccable? Is not our vocabulary too strictly professional? Does it not cramp the intelligence and impair perception? Ought we not to " break their bonds asunder," and learn thoroughly to use the master-tool—English?

NOTE BY THE AUTHOR.

At the instance of Professor Kent, of Syracuse, I add to the "Chamber of Horrors" the expression "the data is limited," as an example of mistaking a plural for a collective.

T. J. J.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 3, 1903.

TRAINING AN ARTIST IN THE FORCES OF NATURE.

BY E. H MULLIN.

If we go back in the history of our language to the first known use of the word " education," we find that in 1540 it had as its meaning " the process of nourishing or rearing a child or young person." It will be noticed that in this case, as in so many others, a term which may now be regarded as meaning something abstract and psychological is derived by metaphorical extension from an earlier concrete and physical concept. Yet if the word " education "has gained in breadth since its first use four and a half centuries ago, it has also lost much in depth—at least as commonly used. The essence of the word " nourishing " is assimilation; it conveys the idea of the food which is most easily converted into life-giving blood, and thence, with hardly a pause, into nerves, bones and muscles, to become an inseparable part of our bodies. For one reason or another, we seem to have passed beyond the stage of a simple educational diet which can be thoroughly assimilated; we present either the jaded palates of a worn-out race, or the capricious appetites of spoiled children. Instead of the educational roast and boiled joints of our forefathers, we toy with highly seasoned *entrées* which blunt our appetites for the time being, but do not give us the strength for long fasts, the energy for great work, or the physical repose necessary for deep thought.

We shall find, if we keep the idea of assimilation as the primary attribute of all education, that the physical and mental analogies are reasonably close and hardly, if at all, misleading. Mental indigestion from over-stuffing, no less than physical indigestion, produces cloudiness of the brain. Mental dyspepsia may follow

a diet of too large a variety of elective courses, just as physical dyspepsia may follow over-indulgence in highly spiced but non-assimilative foods. In both cases time is an indispensable factor to assimilation; plain food will be most enduring in results; maximum efficiency will be found in maximum assimilation and minimum waste. Fixed habits are perhaps the most valuable gift we can receive, whether from home rearing, from college training, or from that first part of our lives passed in the world of men. Yet granted that we have taken a firm hold of essentials, we may pursue cognate non-essentials as an enlightening means of recreation. Every author has his historical background; every science has its borderland; every art has its path of development. Knowledge is the result of profound study; culture is the reward of diligent exploration. With knowledge alone we are as flat-landers, realizing our neighbors only when we touch them; by the aid of culture we can rise above our surroundings, and, by viewing the relation of our neighbors to each other, form a juster estimate of our relation to them.

For, in our realization of our true relationship to the whole of the outer world lies the benefit of our education. The pure specialist, without sympathy and without comprehension is simply a machine tool in the hands of a higher order of intelligence. When Mr. Carnegie claimed for himself only the power of acting as a magnet for much abler men, he either meant much more than he said, or said much more than he meant. To utilize ability, to turn it into its proper channels, to mark the time and place when and where one kind of specialized mind should begin and where it should stop to allow the next specialized mind to take up the running, is the function of true greatness. The general in command of armies, the statesman responsible for a party, the captain of industry with success or failure hanging upon his decision, asks no more than that the subordinate whom he chooses can convert his ideas into action. "Be bold, be bold, be not too bold," said the ancient sage. "Specialize, specialize, but don't specialize too much," says his modern analogue.

Capital, modern economists are agreed, is the crystallized savings which can be lent out to reproduce itself in useful work. Is is, in fact, stored energy. In its baldest form, capital represents the wheat saved from last year's crop to enable the laborer to garner next year's crop without dying of starvation while next year's crop is growing. In its broadest sense, education is not capital but tools. It is not the knowledge of facts which

makes a man educated but the possession of method. To teach a man to learn how to learn is the true function of education, and to stuff his mind with facts beyond this point is merely to encumber him in pursuing his means of livelihood. It is true that the method of education adopted may, and perhaps should, bear some relation to ultimate ends. The future classical scholar will save himself much annoyance by a diligent study of Greek irregular verbs. The future mechanical or electrical engineer will enjoy an ease, not otherwise procurable, by a thorough mastery of elementary mathematics. But, still, education is not so much intended for the elucidation of old problems as for the tackling of those that are new. And, as a knowledge of facts without the power of ratiocination is worthless for new ventures, and as every problem which meets us in life is a new venture, therefore, method by itself is everything, and facts by themselves are nothing.

The faults of technical education of the present day are that they tend to reproduce a microcosm of real life. Everyone has heard of, or has seen, a typical specimen of the " tank drama," in which there is real water, real horses, a real fire engine, or what not, to heighten the verisimilitude. The technical colleges which attempt to make a blacksmith or a mechanic out of a student, fail, just as the " tank dramas " do, by endeavoring to make their courses a miniature copy of future work instead of making them typical of crises and illustrative of principles. Let us glance for a moment at the two great professions where education, as commonly understood, utterly fails to supply a man with the power of commanding success. It will be acknowledged that painting is an art which requires initiation and instruction. Yet, without genius, without inspiration, even the most skilful painters have been unable to rise above the ranks of medicority. The Italians call Andrea del Sarto " the faultless painter." But, as Symonds says, he lacked inspiration, depth of emotion, energy of thought, and cannot therefore take rank among the great Renaissance painters. Or take again the two typical cases of the Archduke Charles and Major General Halleck, for both of whom it may be claimed they were bright and shining examples of profound technical education in the military art. The genius of Napoleon, not a particularly distinguished student, overthrew with ease the strategy of the Archduke Charles, while all that Halleck's technical knowledge seemed to be able to do for him was to point out every possibility of defeat without inspiring him

to a single means of victory. More recently we have seen Sir John French, the only really successful cavalry general of the South African War, overthrow in the field the reputation which the pedants of Aldershot gave him of not being able to handle a cavalry brigade.

We may gather from these examples, and from others which will occur to the minds of every one, that all that technical education can do is to give each man his chance of success or failure. Genius may be able to dispense altogether with techincal education; inherent stupidity will ultimately sink to its true level, in spite of the most careful collegiate training. In considering educational matters, therefore, we are concerned not with geniuses or with muddle-heads, but with average men. How the average man may be trained for a profession for which he feels within himself some aptitude is the question which it behooves us to answer. And the answer which we should give is to teach methods, to instill principles, to lay deep and sure the foundation of elementary knowledge, and trust the future to take care of itself. We have, therefore, two co-related branches of education to consider—education as an art and education as a science.

Education as an art involves perfect familiarity with a larger or smaller number of facts, according to the purpose to which these are to be devoted. In this age of universal reading and writing we are apt somewhat too hastily to assume that a categorical knowledge of the alphabet and the arithmetical tables is necessary to success in life. Those who have lived in countries where a considerable portion of the population is wholly illiterate must have often been struck by hearing men who could not read use language all but grammatically correct, or by observing intricate accounts made up by mental arithmetic without the aid of either multiplication or division. It must also be remembered that in the Dark Ages kings and bards were usually illiterate, though they were none the less the rulers and inspirers of their times. Education as an art, therefore, must be separated from personality on the one hand and from mere pedantry on the other. We may compare education as an art to a knowledge of the names and functions of the pieces on a chessboard divorced from any knowledge of the game of chess itself. If we can then imagine a series of chessboards, each having more pieces than the one preceding it, and each set of pieces having more complex moves than the set preceding it, we shall have a fair analogy of the gamut of education as an art, from

simple elementary education to the highest classical or mathematical standard. Throughout this series there are things to be known by name—what may be called primary concepts—and these mere names have to be clothed with ideas or attributes or functions, by means of which we may see how far we can utilize them. In other words, in education as an art we have to exercise the faculty of memory, and this memory must be clear and accurate if our minds are always to have their tools at hand ready for instant use. But this in turn implies familiarity and familiarity implies constant practice for a longer or shorter time. Here again our average education for the average man comes in. If we have in mind only the first 25 per cent. of our pupils—the geniuses and the hard-reading men—we shall pass along to the next stage before our 50 per cent. of average men have had time to become perfectly familiar with the facts and their connotations which are being studied. If, on the other hand, we attempt to wait for the last 25 per cent. of our pupils—the incorrigibly idle and muddle-heads—we shall waste the time of our 50 per cent. of average men. In every stage of education as an art we have therefore two things to consider, namely, the accumulation of a sufficient number of names and their connotations to give us an ample nomenclature or set of tools, and also enough familiarity with this nomenclature or set of tools to enable us instinctively to select the right tool and to use it efficiently.

Let us now pass to education as a science. A man might know the dictionary from end to end, and yet not be able to use more than one thousand words of it for any particular purpose. Having obtained our tools through education as an art, the problem in education as a science is not to use them as we have been taught but to apply them to new problems. To go back to our former illustration we must be able to play the game of chess after having learned the names of the pieces and their functions. It took the world 2,000 years to find out that deductive logic could state nothing new beyond what was contained in the premises. Science, we are told, is organized and classified knowledge, and the first thing a truly educated man will do with a new fact is to place it under its proper classification—that is, he will refer it to the principle which governs facts of a similar kind. Not only, therefore, is memory needed here but imagination. A man's whole education goes for nothing if in dealing with a new fact he cannot see resemblances in it to other facts where none outwardly exist, or cannot see profound differences between a new

fact and an old one where the outward resemblance is strong. And the highest function of education as a science is to make a man of average ability see resemblances and differences in cases where he would otherwise be blind. Indeed, genius itself, as we see it in the great inventors, is usually nothing more than the power of classifying a fact under its proper generalization and then re-stating it in terms of some other fact classed under the same head.

Rising stage by stage, therefore, according to the future for which our educational requirements are to fit us is our elementary knowledge plus perfect familiarity in dealing with and handling it. Better, far better, that we should know little but be on terms of perfect familiarity with that little, than we should know much and have to grope for what should spring to our minds as quick as thought itself. The time spent, the labor involved, in obtaining an absolute mastery over our primary concepts or elementary knowledge marks the difference in our future work between having strange tools to handle and having tools which so fit into our hands as to become an inseparable part of ourselves.

Let us turn now to the education of an engineer. The definition of an engineer, according to Telford, is one who applies the forces of nature to the service of man. Mr. Mansergh, recently President of the Institution of Civil Engineers, quoted with approval an American definition of an engineer as "a man who could do for one dollar what any fool could do for two dollars." Perhaps the best definition will lie somewhere between these extremes. If a man does not know how to apply at least one form of the forces of nature to the service of man he is not an engineer; and if he cannot do this more economically than an outsider no capitalist with common sense will employ him. An engineer differs from a physician or a lawyer in that patients die and cases are lost without damaging the reputation of a member of either of these professions, while, on the other hand, an engineer's work must speak for itself. The motto over Sir Christopher Wren's tomb in St. Paul's might be adopted as that of the engineering profession as a whole, "*Si monumentum requiris circumspice.*" Posterity camps on the trail of the engineer, and its conclusions, like the judgments of the Lord, are true and righteous altogether. Whether it be the aqueduct of Rome or the Brooklyn Bridge, whether it be a generator at Niagara Falls or the switchboard of a New York power station, it will either form a model from which other generations of engineers will expand into new conceptions

to meet new needs, or it will become a beacon post to point out the way which is to be avoided. Verily, it is no light thing to train up an artist in the forces of Nature!

Let us begin with the prime essential. Without reverence for great works and for the great men by whose agency they were brought forth, there will be no great engineers. Granted that, a sound knowledge of one's native tongue is the best substructure. The great engineers who have been deprived of this aid, have borne eloquent testimony by their efforts at self-improvement in later life to what they considered would have been its usefulness at an earlier period of their careers. An elementary knowledge of Latin is almost indispensable to the clarification and consolidation of the knowledge of nearly every European tongue. Next to these my vote would go to a good working knowledgeo f French because besides its obvious advantage as a language to be spoken, it imparts lucidity and precision to writing—a thing, by the way, which mathematics often fails to do. Early practice in mechanical drawing should also be given to every boy who feels within himself the stirrings to become an engineer, because familiarity with the pencil is easily acquired early in life, but is often one of the greatest stumbling blocks when taken up too late.

Then as to mathematics. As the profession of an engineer always involves constant dealing with quantities and values, he ought to know mathematics as he knows the currency of his native country. In other words, he ought to be able to make change with ease, quickness and accuracy—not as if one were in a foreign country in a constant state of painful reckoning. A thorough knowledge of ordinary mathematics is here prescribed, not any vain ascents with crippled wings into the empyrean. What is meant by "ordinary mathematics" may perhaps be more clearly indicated by a remark and an anecdote. One may make accurate change without any knowledge of the science of numbers. Lord Salisbury, when President of the British Association, told the story of the old Oxford Professor who said to him, fiercely, "What I like about quartenions, sir, is that they cannot be used for any base utilitarian purpose."

This makes our substructure complete. The first part of our superstructure should consist in learning the principles of the applied sciences. These should be studied in books, assisted by oral teaching, and enforced and re-enforced by the practice of dozens or hundreds of examples. If one wants to know how each principle should be learned, he should watch a great singing

teacher train a pupil. A false note in a scale demands a hundred perfect repetitions. A false note in an *aria* means back to the scale for a hundred more repetitions before attacking the *aria* a second time. Why should the future artist in Nature be less carefully prepared for his work? Is that work likely to be less important? Or is it merely because his future audience is less likely to detect a false note?

With this, the education, of our engineer ends or rather begins. He may be fifteen, sixteen or any age. He may have studied in school, or in college, or at home. He is, however, a trained engineering soul, according to the measure of his talents. He is able to learn the art of engineering, or any other art, for which he has an aptitude, in months, where another man of equal ability might take years and not know it half so thoroughly. All he needs to ensure his success in life is to find a master who can utilize his powers.

PRESIDENT SCOTT:—One of the speakers said that an engineer ought not to be judged until he had been in practical experience for, say, 25 years. If you set that standard, then, we cannot begin to receive a verdict on the modern electrical engineer for 10 or 15 years to come. The modern electrical engineer is a new engineer. He has a new kind of work. The census shows that electrical work as represented by the capital invested increases something like 20 per cent. a year. Men are needed rapidly and the followers of engineering, and particularly of electrical engineering, have as their principal function in the world, increasing the efficiency and the effectiveness of modern life; so it behooves these two societies which are represented here to-day to unite and to expend every effort for the more thorough production of efficient engineers.

On motion of President Woodward the Convention adjourned *sine die*.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, September 25, 1903.

The 179th Meeting was held this date at the New York Academy of Medicine, 17 West Forty-third Street,

President Charles F. Scott, of Pittsburg, called the meeting to order at 8.20 o'clock and said:

During the past year the fundamental characteristic of our work has been extension and expansion, both in our various activities and also territorially. I believe that never before have the members of the INSTITUTE throughout the country felt the same direct interest in the INSTITUTE, and the same personal contact with its affairs that they do at this time. I believe that the various movements in several lines, particularly in the organization of local branches, during the past year, are but the beginnings of a great future for the INSTITUTE. We have been laying a foundation upon which a magnificent structure may be erected. It is, therefore, particularly appropriate that our leader, the President of the INSTITUTE, should at this time be a man who represents the Western part of the country. I believe this sentiment is one which has been growing among our members and that the part of the country from which the President as well as our other officers are selected, is becoming a more and more important element in the choosing of our officers.

It is, therefore, with great pleasure that I now turn over the Presidency of the INSTITUTE to my successor, and introduce to you the man whom you have chosen for your President, Mr. Bion J. Arnold, of Chicago.

PRESIDENT'S ADDRESS.

Members of the Institute:

Our new Constitution does not call for a formal address from the incoming President at the time of his inauguration, as this duty is required of him at the annual convention. My worthy predecessor, however, outlined his course on taking office and followed it so well and with such signal benefit to the INSTITUTE, that his action prompts me to, briefly, point out the lines which I believe we should follow during the coming year.

The remarkable development and growth of our body during the past two years has introduced many new elements which must stand the test of time and possibly be tried in a period of financial depression. Our energies, therefore, should be directed toward carrying forward the work, so well started by my predecessors, upon conservative lines which will insure its permanency and result in the greatest good to the INSTITUTE.

First.—For obvious reasons our recent great rate of increase of membership cannot continue indefinitely, and our expenditures should therefore be gauged to meet this condition.

Second.—Our local branches should, if possible, be made to last after the enthusiasm, born of novelty, has worn off, which implies encouragement from headquarters and sustained effort on the part of the local members.

Third.—The work of our special committees in connection with electrical engineering standardization and the collection of technical data should be encouraged and additional committees appointed to extend the work in other promising directions.

Fourth.—We should allow the authors of our papers more time for presenting them, and our members more time for their discussion, even, if to accomplish this, we are compelled to have fewer papers.

Fifth.—Contributions making provision for our interest in the land for the engineering building should be placed in a separate fund which should be set apart from all other INSTITUTE funds and to which should be credited all funds for building purposes now on hand, and subsequently received for such purposes from donations or from the sale of bonds or other securities.

Sixth.—Our library fund should also be carried as a distinct fund and all donations and appropriations for library purposes credited to it, all expenditures for library purposes to be debited to this fund.

Seventh.—On account of the International Electrical Congress to be held at St. Louis in 1904, we shall be called upon not only to contribute to the scientific value of this congress, but to receive and entertain many distinguished guests and members from foreign countries. Our plans should, therefore, be so well and broadly laid and executed that our guests shall return home not only fully repaid for their visit among us, but shall also feel that the splendid hospitality which was shown us as a body on our trip abroad in 1900, and to our individual members before and since, has been fully appreciated.

Eighth.—Our relationship with the other large engineering societies of this country have, during the past year, become more intimate, and we are now about to join with them in the ownership and management of a union engineering building which shall meet the needs of all. The general preliminaries have been perfected and the work of the coming year will consist in the crystallization of the plans and the origination of definite means and methods for raising funds and for promoting the material progress of the work.

I trust we may be able to carry to a successful conclusion the work so splendidly initiated by my predecessor, Mr. Scott, and his able lieutenants, and in such a manner as not only to retain but to heighten the respect and good will of those who may coöperate with us; and by the adoption of rational methods and the exercise of good business judgment, in carrying on the work, insure that the generous gift of Mr. Carnegie to the engineering profession shall in its material culmination attain the ideal that he hoped for.

I wish to express my appreciation of the confidence you have shown in me by placing me at the head of this INSTITUTE, the youngest, yet one of the most progressive of the several great engineering bodies of this country. I sincerely thank you and I feel that you will accord to me such harmony of action and support that the coming year may be of the greatest benefit to our membership and add in some slight degree to the prestige of the engineering profession at large.

SECRETARY POPE :—At a meeting of the Board of Directors this afternoon the following Associates were elected :

Name.	Residence.	Endorsers.
APPERSON, ALFRED HULL,	Assistant Electrician South Eastern Tariff Association, 433 Equitable Building, Atlanta, Ga.	A. M. Schoen. J. A. Wotton. E. W. Trafford.
BABCOCK, EDWIN WILSON,	Superintendent of Electrical Construction, Brooklyn Edison Co., Edison Building; res., 272 Ryerson St., Brooklyn, N. Y.	C. S. MacCalla. W. S. Barstow. Cabot Stevens.
BARRY, CHARLES EDWARD,	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A. L. Rohrer. H. G. Reist. H. C. Wirt.
BLACKWELL, HENRY FIELD,	Electrical Engineer, Department of Water Supply, etc.; res., 18 Morningside Ave., New York City.	T. C. Martin. G. F. Sever. H. C. Cushing, Jr.
BOWDEN, ZOLLY MASBY,	Student General Electric Co.; res., 615 State St., Schenectady, N. Y.	R. N. Williams. C. P. Steinmetz. E. B. Raymond.
BRIERLEY, DANIEL HENRY,	Electrician Bell Telephone Co., Laurel Springs, N. J.	G. W. Pickard. M. E. Leeds. R. W. Pope.
BROOKS, IRVING EMERSON,	Draftsman, Chicago Edison Co., 139 Adams St.; res., 551 Jackson Boulevard, Chicago, Ill.	B. J. Arnold. Peter Junkersfeld. W. G. Carlton.
BROWN, FRANK ZENAS,	Consulting Engineer, Richmond Engineering Co., 1117 Grove Ave., Richmond, Va.	A. J. Pizzini. E. W. Trafford. Joseph Sachs.
BROWN, GARRY ESTEP,	Construction Department, Niagara Falls Power Co., Niagara Falls, N. Y.	H. W. Buck. P. M. Lincoln. E. B. Raymond.

CALVERT, RICHARD C. M., Chief Operator, Cauvery Power Scheme, Champion Reefs, Mysore State, India.	W. B. Potter. M. A. Oudin. R. W. Pope.
CARLIN, WILLIAM HENRY, Electrical Engineer, H. Eckstein & Co., Johannesburg, S. A.	A. W. K. Peirce. J. W. Kirkland. R. W. Pope.
CHEEVER, MARKHAM, Engineering Department, The Ontario Power Co.; res., The Alexandria, Niagara Falls Centre, Ontario.	H. S. Carhart. V. G. Converse. G. W. Patterson, Jr.
CLIFF, RICHARD CHARLES, Electrical Engineer, Tyer & Co., Ashwin St., Dalston Junction, London, N. Eng.	John Denham. William Maver, Jr. R. W. Pope.
CLOHESEY, THOMAS F., Manager Electrical Department, Newburgh Light, Heat and Power Co., 104 Water St., Newburgh, N.Y.	A. Parshall. C. W. Price. William Maver, Jr.
COKEFAIR, FRANCIS ALBERTSON, Chief Engineer, Great Northern Power Co., Duluth, Minn.	J. H. Finney. E. C. Bacot. M. H. Gerry, Jr.
CONKLING, DEWITT C., Inventor and Model Maker; res., 14 Third St,. Hoboken, N. J.	E. P. Thompson. J. E. Winn. R. W. Pope.
CRUMPTON, WILLIAM JAIRUS, Student, University of Wisconsin; res., 1111 Maple Ave., West Superior, Mich.	W. B. Jackson. D. C. Jackson. C. F. Burgess.
DAVIS, FRED HORNE, Engineer, Westinghouse E. & M. Co., Johannesburg, S. A.	C. F. Scott. H. P. Davis. R. W. Pope.
DE BLOIS, LEWIS AMORY, Electrical Engineer, 48 Gloucester St.,Boston,Mass.	M. L. Holman. C. A. Adams, Jr. D. W. Roper.
DINSMORE, SAMUEL C., Expert Nutrition Investigation U. S. D. A., Wesleyan University; res., 173 High St., Middletown, Conn.	William Maver, Jr. R. W. Pope. E. B. Rosa.
DOBBELAAR, EDWARD CHRISTIAN, Assistant Engineer, New York *Sun*, 170 Nassau St., New York City; res., Edgewater, N. J.	E. G. Benjamin. Samuel Sheldon. S. W. Ashe.
DOLPH, JOHN CLEMENT, Manager, Insulating Varnish Department, Standard Varnish Works; res., 19 Revere Place, Brooklyn, N. Y.	Max Osterberg. Alex. Henderson. E. S. Keefer.
DOTY, ERNEST LAWRENCE, Assistant Engineer, Westinghouse E. & M Co., 11 Pine St.; res., 2 W. 120th St., New York City.	R. L. Wilson. W. N. Ryerson. W. S. Rugg.
DRANE, FRANK NEAL, Secretary and Treasurer, Corsicana Gas & Electric Co., Corsicana, Tex.	F. A. Jones. James Lyman. B. E. Sunny.
DUFRESNE, BERNARD MAURICE, Erecting Engineer, Westinghouse E. & M. Co.; res., 627 South Wesley Ave., Pittsburg, Pa.	C. F. Scott. W. K. Dunlap. H. P. Davis

EDMUNDS, CHARLES KEYSER, Professor of Physics, The Christian College of China, Canton, China.	J. B Whitehead, Jr. L. M. Potts. C. T. Hutchinson.
FARLEY, J. WALDRON, Transformer designer, Westinghouse E. & M. Co., Pittsburg, Pa.	J. S. Peck. C. F. Scott. C. E. Skinner.
FITZ, ERVIN MOUL, Electrical Engineer, M. P. Dept., Pennsylvania Lines West of Pittsburg, 295 N. High St., Columbus, Ohio.	B. V. Swenson. M. C. Hunter. R. T. E. Lozier
FLEMING, THOMAS JOSEPH, Electrical Engineer, British Thomson-Houston Co., Ltd., 83 Cannon St.; res., 94 Clements Inn, Strand, London, Eng.	E. G. Waters. W. J. Clark. Theodore Beran.
FLICKINGER, JOHN TRESSLER, Head of No. 16 Test, General Electric Co., Schenectady, N. Y.	Howard Maxwell. E. B. Raymond. R. N. Williams.
FULLER, LUCIUS B., Assistant to P. N. Nunn, The Niagara Construction Co., Ltd., Niagara Falls, N. Y.; res., Bozeman, Mont.	P. N. Nunn. P. H. Thomas. V. G. Converse.
GIBBES, THOMAS MIDDLETON, Assistant to Contract Agent, Georgia Railways and Electric Co., Atlanta, Ga.	William Maver, Jr. R. W. Pope. C. E. Hardy.
GIBBS, GEORGE SABIN, 1st Lieut., Signal Corps, U. S. A., Washington, D.C.	William Maver, Jr. R. W. Pope. Edgar Russel.
GILCREST, CHARLES F., Testing Department, General Electric Co.; res., 250 Union St., Schenectady, N. Y.	C. L. Cory. J. N. LeConte. W. H. Allen.
GILMAN, RALPH EDSON, Engineer, The British Westinghouse E. & M. Co., Ltd., Manchester, Eng.	P. M. Lincoln. C. F. Scott. B. G. Lamme.
GODDARD, STEPHEN HAILE, Secretary and Manager, *Electrical Review*, 13 Park Row; res., 223 Fifth Ave., New York City.	J. J. Carty. C. W. Price. W. H. Browne, Jr.
GOULD, EDWARD FREDERICK, Railway Engineering, Department, General Electric Co., Schenectady, N. Y.	A. H. Armstrong. H. B. Smith. J. E. Woodbridge.
GREGORY, JOHN PUGH, Engineer Power and Lighting Departments, The British Thomson-Houston Co. Ltd., Rugby, Eng.	H. F. Parshall. Evan Parry. E. G. Waters.
HALL, WILLIAM H., Head of Department of Science, Baltimore Polytechnic Institute; res., 1215 N. Eden St., Baltimore, Md.	H. P. Suman. J. H. Finney. M. C. Schwab.
HALLER, WINFIELD A., Engineer, Sanderson & Porter 52 William St.; res., 509 W. 124th St., New York City.	L. A. Phillips. W. S. Rugg. E. N. Sanderson.

HANCOX, SAMUEL HERBERT, Electrician in charge Locomotive Workshops, Queensland Government Railways, North Ipswich. Queensland, Aus.	F. A. McCarty.	W. G. T. Goodman. J. M. Jolly.
HARRIS, CHARLSE ORRIN, Engineer and Superintendent, Rochester Telephone Co.; res., 59 Stone St., Rochester, N. Y.	J. R. Putnam.	G. A. Redman. R. W. Pope.
HART, PERCY E., Electrical Engineer, Canadian General Electric Co., 14 King St. E., Toronto, Ont.	R. T. MacKeen.	J. Kynoch R. W. Pope
HAYES, STEPHEN Q., Switchboard Engineer, Westinghouse E. and M. Co.; res., 4 Brushton Ave., Pittsburg, Pa.	H. P. Davis.	C. F. Scott. Louis Duncan.
HITNER, HARRY FERMAN, Electrical Engineer, American Window Glass Co., Arnold; res., Pittsburg, Pa.	S. B. Martin.	H. G. Sage. C. C. Badeau.
HOFFMAN, FRANK, Electrical Engineer, The St. Joseph Lead Co., Bonne Terre, Mo.	C. G. Burton,	S. M Bushnell. J. F. Gilchrist.
HOGAN, THOMAS JEFFERSON, New York Edison Co., 57 Duane St.; res., 611 E. 148th St., New York City.	H. G. Stott.	W. G. Carlton. H. B. Gear.
HOGLE, CHARLES EDWARD, Acting Foreman of Testing Department, The Edison Electric Co., Los Angeles, Cal.	C. A. Copeland.	F. A. C. Perrine. F. V. T. Lee.
HOLDBERG, HENRY ATKINSON, Manager Citizens Gas and Electric Co., Council Bluffs, Ia.	J. G. Wray.	A. S. Hibbard. R. W. Pope.
HOLDEN, EDGAR B., JR., Constructing Engineer, General Electric Co., Niagara Falls, N. Y.; res., 262 Hamilton St., Albany, N. Y.	W. L. R. Emmet.	H. W. Buck. W. G. Ely, Jr.
HOWELL, DAVID JANNEY, Secretary-Treasurer and Manager, Welch Water, Light and Power Co., 605 12th St., N. W., Washing- D. C.	Charles Hodge.	H. H. Seabrook. R. W. Pope.
JACOBUS, DAVID SCHENCK, Professor Experimental Engineering, Stevens Institute of Technology, Hoboken; res., 83 Grand St., Jersey City, N. J.	A. F. Ganz.	Oberlin Smith. J. M. Smith.
JESSUP, WARREN CANFIELD, Sales Engineer, The Cutler Electric and Mfg. Co.; res., 1728 Spring Garden St., Philadelphia, Pa.	H. A. Lardner.	G. F. Sever. W. M. Scott.
JOHNSON, JASON A., Electrician, Niagara Falls Power Co.; res., 544 10th St. Niagara Falls, N. Y.	L. E. Imlay.	P. M. Lincoln. W. K. Gibboney.
JOHNSON, JOHN, C. Electrician, Westinghouse E. & M. Co.; res., 31 West Clinton St., Cleveland, Ohio.	William Maver, Jr	Townsend Wolcott R. W. Pope.

JOHNSTON, JAMES EWING,	Engineer and Superintendent, Mountain Electric Co.; res., 1111 Detroit St., Denver, Colo.	J. W. Stearns. P. N. Nunn. R. D. Mershon.
KENYON, ALFRED LEWIS,	Electrical Engineer, General Electric Co., Schenectady, N. Y.; res., Lima, Peru, S. A.	M. A. Oudin. W. G. Ely, Jr. V. D. Moody.
KONISHI, TAMENOSUKE,	Investigating Engineer, Shibaura Engineering Works, Tokyo, Japan.	Z. Iijima. M. Namba. S. Misaki.
LA FEVER, CHARLES A.,	Assistant Superintendent and Electrical Engineer, Advance Thresher Co., 75 Garrison Ave., Battle Creek, Mich.	H. S. Carhart. T. P. Gaylord. Arthur Hartwell.
LANG, ARTHUR GORDON,	Tester, Edison Storage Battery Co., Glen Ridge, N. J.	George Hays. R. A. Fliess. J. W. Aylsworth.
LARKE, WILLIAM JAMES,	Manager, Power and Mining Dept., British Thomson-Houston Co., Ltd.; res., 59 Hillmorton Road, Rugby Eng.	S. B. Paine. E. E. Fuller. Arthur Churchill.
LAWTON, EDWIN FRANKLIN,	Superintendent, Hartford Electric Light Co., 100 Sargent St., Hartford, Cn.	H. J. Blakeslee. R. W. Pope. W McA. Johnson.
LYSTER, THOMAS LEE BRENT,	Electrical Engineer, 402 Jefferson Ave., Detroit, Mich.	H. J. Ryan. H. H. Norris. G. S. Macomber.
MACHALSKE, FLORENTIN JOSEPH,	Chemist, Brooklyn, N. Y.	C. F. Burgess. W. McA. Johnson. N. S. Keith.
MANGE, JOHN I.,	Superintending Engineer, Plattsburg Light, Heat and Power Co., Plattsburg. N.Y.	G. M. Cole. C. D. Haskins. G. F. Sever.
MARSHALL, FREDERICK JOSEPH,	City Electrician, The Corporation of the City of Kamloops, Kamloops, B.C.	R. B. Hamilton. Wm. Maver, Jr. R. W. Pope.
MCCLASKEY, WILLIAM TYNDALE,	Manager, Societè Anonyme, Westinghouse, Atacha 32 Madrid, Spain.	C. I. Young. F. B. H. Paine. E. W. T. Gray.
MCDONALD, WALTER D.,	Salesman, Westinghouse E. & M. Co, 171 La Salle St., Chicago, Ill.	C. W. Regester. J. J. Gibson. Ervin Dryer.
MCPHERSON, NORMAN CRAWFORD,	Engineering Department Westinghouse E. & M. Co.; res., 4924 Center Ave., Pittsburg, Pa.	P. M. Lincoln. C. F. Scott. Charles Hodge.
MEAD, GEORGE ALVIN,	Chief Engineer, The Ohio Brass Co., Mansfield, Ohio.	D. C. Jackson. C. F. Burgess. G. W. Knox.
MIEHLING, RUDOLPH,	Sales Engineer, Walker Electric Co., 2318 Noble St.; res., 4513 Uber St., Philadelphia, Pa.	F. S. Perry. C. C. Badeau. W. M. Scott.

MIXER, CHARLES ADAM, Civil and Hydraulic Engineer, Rumford Falls Power Co., Rumford Falls, Me.	C. W. Lyman. G. L. Nicholson. B. L. Baldwin.
MORDOCK, CHARLES T., Superintendent, Lighting and Power Department, Terre Haute Electric Co., Terre Haute, Ind.	A. L. Mudge. Russell Robb. H. J. Ryan.
MURPHY, JOHN J. Chief Engineer, Chicago Union Traction Co.; res., 1948 Lexington St., Chicago, Ill.	T. P. Bailey. B. E. Sunny. James Lyman.
NEWELL, HARVEY EDGAR, India Rubber and Gutta Percha Insulating Co.; res., 101 North Broadway, Yonkers, N. Y.	A. F. Ganz. F. J. Hall. M. J. Insull.
NEWTON, SAMUEL OSCAR, North East Electric Light and Power Co., North Pitcher; res., 607 W. Water St., Elmira, N. Y.	H. M. Bengler. B. C. Wolverton. W. W. Cole.
NORTH, GILBERT, Electrical Engineer, British Westinghouse E & M.. Co.; res., 325 Hudson St., Hoboken, N. J.	A. F. Ganz. Peter Wright. J. H. Cuntz.
NOYES, ERNEST HIGH, Manager of Chicago Office, The Pittsburg Reduction Co., 190 Monroe St., Chicago, Ill.	J. H. Finney. W. G. Carlton. R. W. Pope.
OKAMOTO, KEITARO, Chief Engineer, The Hiroshirma, Suirioku Denki Kaisha, Hiroshima, Japan.	G. A. Harris. F. B. H. Paine. C. I. Young.
PANTER, THOMAS ALFRED, Assistant Electrician, The Niagara Falls Power Co.; res., 481 19th St., Niagara Falls, N. Y.	W. K. Gibboney. L. E. Imlay. H. W. Fisher.
PARKER, HOMER CHARLES, Salesman J. Martin & Co., 31–33 New Montgomery St.; res., 1601 Taylor St., San Francisco, Cal.	F. V. T. Lee. F. A. C. Perrine. C. C. Chesney.
PATTISON, HUGH, Electrical Engineer, Westinghouse Church, Kerr & Co., 10 Bridge St.; res., 223 W. 38th St., New York City.	C. T. Hutchinson. Louis Duncan. F. J. Sprague.
PECK, RANSOM B. W., Electrician in charge Kingsbridge Power Station, Interurban Street Railway Co.; res., 213 W. 104th St., New York City.	F. G. Clarke. J. J. Mahony. W. N. Ryerson.
PICKERING, FRANK, The Assistant Electrical Engineer, The Cape Government Railways, Cape Town, S.A.	John Denham. J. E. Lloyd. J. H. Hamilton.
POST, HOWARD MELVIN, Telephone Engineer, Kellogg Switchboard and Supply Co.; res., 4211 Berkley Ave., Chicago, Ill.	W. W. Dean. F. J. Dommerque. K. B. Miller.
PUDAN, HERBERT WHATMOUGH, Chief Electrician, The Randfontein Estates and Bold Mining Co., Ltd., Randfontein,Transvaal,S.A.	J. W. Kirkland. William Maver, Jr. R. W. Pope.

RADLEY, GUY RICHARDSON,	Foreman Meter and Testing Department, The Milwaukee Electric Railway and Light Co.; res., 3226 Chestnut St., Milwaukee, Wis.	Peter Junkersfeld W. S. Aldrich. R. W. Pope.
RITTENHOUSE, WALTER B.,	Mechanical Engineer, Great Northern Power Co., 315 Providence Building, Duluth, Minn.	M. H. Gerry, Jr. J. H. Finney. E. C. Bacot.
ROEDING, HENRY ULRICH,	Sales Engineer, Jno. Martin & Co., 31–33 New Montgomery St.; res., 1910 Washington St., San Francisco, Cal.	F. V. T. Lee. F. A. C. Perrine. C. C. Chesney.
ROSSMAN, JAMES G.,	President B. R. Electric Co., 52 Peachtree St., Atlanta, Ga.	A. M. Schoen. C. D. Haskins. J A. Wotton.
SCARFE, GEORGE,	Division Superintendent, California Gas and Electric Co., Nevada City, Cal.	C. W. Hutton. L. M. Hancock. F. G. Baum.
SCHREIBER, HERMAN VICTOR,	Chief Engineer, Augusta Railway and Electric Co., Augusta, Ga.	H. T. Brown. J. P. Edwards. A. J. Rowland.
SESSIONS, WALTER SAMUEL,	Operator, The Pacific Electric Railway Co.; res., 526 So. Bonnie Brae St., Los Angeles, Cal.	D. E. Clough. L. E. Reynolds. C. L. Cory.
SHAW, ALONZO BENJAMIN,	Electrician, Edison Electric Illuminating Co., of Boston; res., 435 Quincy St., Dorchester, Mass.	Sidney Hosmer. H. S. Anderson. L. D. Bliss.
SHEPHERD, FRANK ROLAND,	Assistant Engineer and Business Manager, Noyes Brothers; res., Roslyn, Dunedin, N. Z.	William Maver, Jr. R. W. Pope. W. G. T. Goodman.
SIMON, ARTHUR,	Electrical Engineer, Cutler-Hammer Co., 309 21st Street, Milwaukee, Wis.	F S. Wilhoit. A W. Berresford. E. Kittler.
SPURRIER, JOHN RUDOLPH,	The British Westinghouse E. & M. Co., 295 Urmston Lane, Stretford, Manchester, Eng.	C. F. Scott. H. P. Davis. C. E. Skinner.
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STEVENSON, FRANCIS LESLIE,	Electrical Engineer, International Harvester Co., Fullerton and Cloyborne Ave., Chicago, Ill.	B. J. Arnold. W. S. Aldrich. Jas. Lyman.
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WARNER, ARTHUR P.,	Northern Electric Mfg. Co., res., 4339 Berkeley Ave., Chicago, Ill.	J. H. Finney. J. T. Kelley. S. K. Colby.
WAY, SYLVESTER BEDELL,	Superintendent, Union Electric Light and Power Co., 1728 Oregon Ave., St. Louis, Mo.	Gerard Swope. H. H. Humphrey. B. J. Arnold.
WESSELHOEFT, CHARLES DIETRICH,	Electrical Engineer, Kohler Brothers; res., 749 So. Sawyer Ave., Chicago, Ill.	C. A. Dresser. Morgan Brooks. W. H. Browne Jr.
WHEELER, WALTER SCOTT,	Superintendent Franchise Department, Board of Public Works, 915 26th Ave., South Seattle, Wash.	P. H. Knight. D. P. Robinson. R. W. Pope.
WIECHMANN, FERDINAND G.,	Consulting Chemist, The Sawyer-Man Electric Co.; res., 310 West 80th St., New York City.	F. B. Crocker. F. S. Smith. H. M. Cogan.
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ZAPP, LOUIS MILTON,	Indiana Union Traction Co., Newton Claypool Building, Indianapolis, Ind.	W. E. Goldsborough. C. P. Matthews. R. W. Pope.

Total, 108.

APPLICATIONS FOR TRANSFER FROM ASSOCIATE TO THE GRADE OF MEMBER. FIRST READING.

Recommended by Board of Examiners, Friday, Sept. 11, 1903.

WILLIAM HOWARD COLE, Constructing Engineer, Dick Kerr & Co., Singapore.

WALTER ATWOOD HALL, Designing Engineer, General Electric Co., Lynn, Mass.

WILLIAM WEEDON COLE, President and General Manager, Elmira Water, Light and Railway Co., Elmira, N. Y.

WALTER I. SLICHTER, Electrical Engineer, General Electric Co., Schenectady, N. Y.

A paper presented at the 179th Meeting of the American Institute of Electrical Engineers, New York, Sept. 25, 1903.
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AN EFFICIENT HIGH-PRESSURE WATER-POWER TRANSMISSION PLANT.

BY GEORGE J. HENRY, JR., AND JOSEPH N. LE CONTE.

An interesting hydraulic electric power transmission plant has recently been started in Southern California by the Edison Electric Co., of Los Angeles. The water pressure or head employed is equal to 1960 feet vertical fall, which is obtained in something over 8000 ft. length of pipe-line. This gives an effective pressure—after making allowances for friction loss—of considerably over 1900 ft. head, or 825 lbs. per sq. in., equal to 55 atmospheres.

The station is located about ten miles from Redlands, in Southern California, and is used on an extensive system, including a number of other power stations, for transmitting power to Los Angeles and largely for irrigation pumping in the San Gabriel Valley—celebrated for its oranges and other tropical fruits.

The generators are of 750 k.w. normal capacity each, running at 430 revs. per min., and the water wheels are of the tangential type and mounted on the same shaft as the rotor. This shaft is 9″ in diam. where the wheels are pressed on, and is of forged steel, carried in three generator ring-oiling bearings—the water wheel being located in what would ordinarily be the pulley compartment of the generator. The box bed-plate of the generator is enlarged to surround the water-wheel pit, and has an opening of 3 ft. 4 in. ×10 ft. 2 in., and is planed and fitted along water-tight joints with the water-wheel housings. These are thoroughly stiffened with internal ribs and provided with centrifugal discs and pockets for preventing leakage of water from the

interior of the wheel compartment to the outside, entirely without friction.

Each generator is fitted with a single wheel or runner, which, on account of the enormously high peripheral speed of 170 ft. per second, is made of a special rolled-steel plate, thoroughly annealed and turned to eliminate all shrinkage strains. The high speed involved is entirely beyond the limits of safe practice for cast

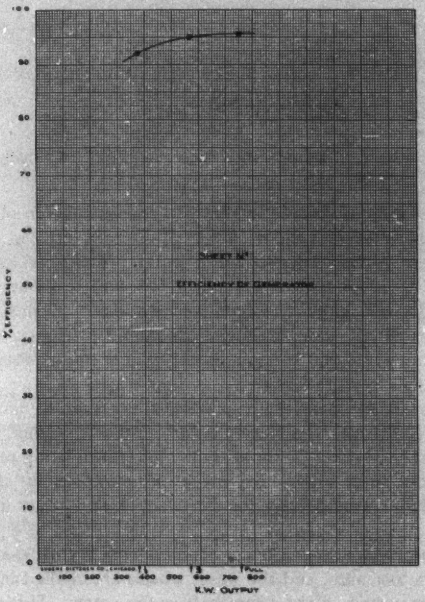

FIG. 1.

iron, and large cast steel discs contain such dangerous shrinkage strains, in spite of the ordinary annealing process, that it becomes dangerous to employ them under such high water pressures. In addition to the centrifugal strains in the rim of a wheel of this character, we have the strains due to water impact on the buckets. This amounts to about 22,000 on the front bolt of each of the buckets.

The buckets are of soft open-hearth steel castings, thoroughly

annealed and machine ground, and polished on the inside to give perfectly smooth and true curved surfaces for the water to flow over. The front edge and centre knife of each bucket is dressed to a perfectly true cutting edge and carefully centred on the wheel rim. The buckets are cast with heavy internal projecting lugs, which are milled out and driven over the wheel centre rim.

The wheel hubs consist of heavy semi-steel castings, to which the steel disc is securely bolted by turned nickel-steel bolts

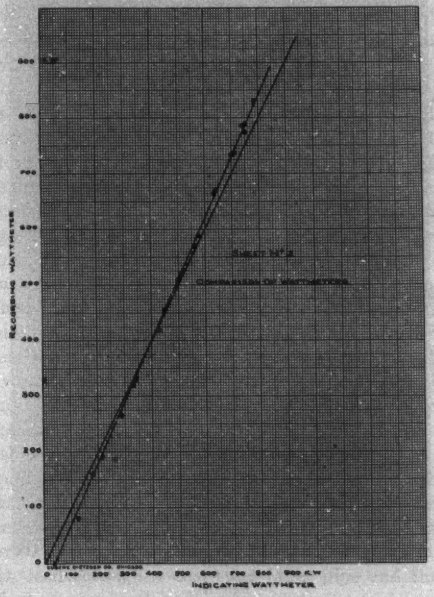

FIG. 2.

driven in reamed holes. This disc is turned perfectly true all over, and carefully adjusted to a running balance at 430 revs. per min. In actual operation about 200 buckets come under the action of the high pressure water jet every second.

The wheels were built for a maximum overload capacity of 50 per cent., and for continuous service of 24 hours a day and 365 days in the year, and no trouble is experienced from the cutting

of the buckets and nozzles by the high pressure water, as after five months' operation the wear is almost imperceptible. The water is usually clear, except for an occasional storm, during which considerable sand and gravel may be washed down into the reservoir at the top of the pipe-line. The most severe storm known for many years washed considerable sand down the pipe-line just after the wheels were installed and started up, but the

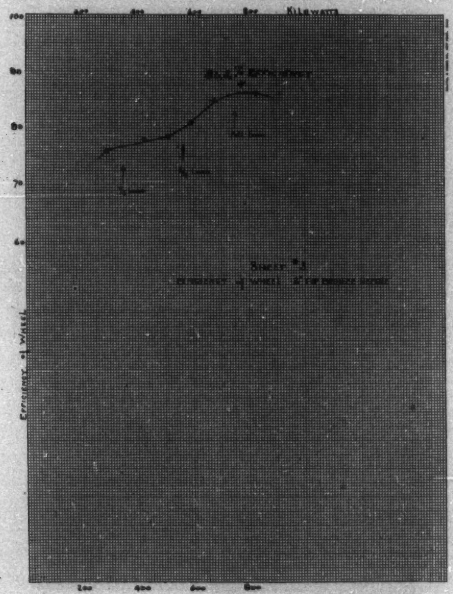

FIG. 3.

steel buckets show no appreciable wear as the result of such severe treatment.

The main pipe-line consists of :

2485 linear feet of 26″ inside diameter sheet-steel riveted pipe, varying in thickness from 14 B.W.G. to 6 B.W.G.

Below this is 2990 linear feet of 24″ inside diameter sheet-steel riveted pipe, made of gauges running from No. 6 B.W.G. to $\frac{5}{16}$ of an inch.

Up to this point the design of the pipe-line is largely in accordance with well-known practice, but from this point down the pipe consists of :

360 ft of 24″ outside diameter $\frac{1}{2}$″ thick, lap-welded steel pipe
260 " " 24″ " " $\frac{9}{16}$″ " " " "
414 " " 24″ " " $\frac{5}{8}$″ " " " "
956 " " 24″ " " $\frac{3}{4}$″ " " " "

And below this:

620 ft. of 24″ outside diameter, $\frac{3}{4}$″ thick, lap-welded steel pipe.

The 20 ft. lengths of the last 620 ft. are jointed together with solid steel flanges welded on the ends of the pipe sections, all of the other 24″ lap-welded pipe being put together with " bump " joints.

At the lower end of this flanged pipe the line branches into two forks, each of which is 18″ outside daimeter of $\frac{5}{8}$″ thickness and 45 ft. in length. From each of these terminals the pipe again branches into two lines, each being 14″ outside diameter and $\frac{1}{2}$″ thick, lap-welded—each branch being 40 ft. in length and terminating just outside of the power house wall in the cast-steel taper pipe immediately above the gates of the water wheels. The branch from the 24″ to the 18″ and the two branches from the 18″ lines to the 14″ are made of heavy annealed-steel castings. The main pipe-line, just before the cast steel Y to the 18″ branches, is supplied with a heavy pressure, outside screw and yoke, 24″ gate valve, and each of the 18″ branch lines are supplied with similar high pressure cast-steel valves so that the water supply to each of the water wheels, or groups of water wheels, may be entirely shut off without emptying the long pipe.

The main pipe is protected from accidental water-hammer by several air-chambers of large capacity with the necessary equipment of charging tubes, to recharge the chambers as the air is carried away in solution. The 14″ branch pipes supplying each unit, feed through a cast-steel taper pipe and through a 10″ single disc, cast-steel body gate valve of outside screw and yoke construction, with Tobin bronze valve stem and with roller bearings for taking up the thrust on the gate-nut in each direction. All of the gate valves are provided with by-passes to reduce the strain when the gates are opened or closed.

The nozzle is one of the most interesting features of the installation. It consists of a combination needle and deflecting nozzle. The deflecting joint is arranged for giving the best possible regulation without water-hammer or shock in the pipe-line,

and water economy is secured by the needle nozzle of the Clemmons type. The deflecting nozzle is fitted with a high pressure ball joint pivoting on nickel steel trunnions, working in oil packed gun-metal bushings and with leather packed ball joint. By the motion of the deflecting nozzle the stream may be easily thrown on or off of the buckets by hand, or automatically by the hydraulic governor. It will be readily appreciated that this

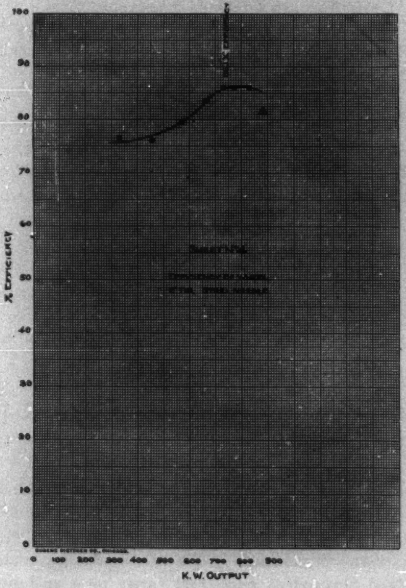

FIG. 4.

enables the operator to vary the power output from the wheel from zero to maximum instantaneously and with very small effort, without in any way varying the velocity of water in the main pipe. Absolutely no shock is thus occasioned in the pipeline by the action of the governor due to fluctuations of the load.

The most accurate regulation is further obtainable owing to the very small amount of inertia in the moving parts—the deflecting nozzle joint weighing but a few hundred lbs. and being

accurately counterbalanced—whereas in turbine installations the unbalanced gates and the inertia of the moving water column seriously interfere with satisfactory regulation. The governor is in no way connected with the operation of the needle, which is for the purpose of regulating the flow of water through the nozzle at different hours of the day, and is accomplished through suitable geared connections to a floor stand located

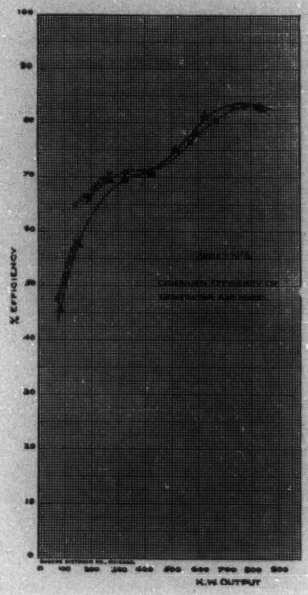

FIG. 5

above the power house floor. The method of operation is as follows:

From previous records the station attendant knows very closely the peak-load that is likely to occur within the hour, and, once an hour, or thereabouts, readjusts the size of the stream so that it will easily carry the peak-load. The governor then takes care of the load fluctuations, maintaining a constant speed at all times by deflecting more or less of the stream from the water

wheel buckets. In this way a very great saving in water over the old deflecting nozzle when used alone is obtained.

By referring to the accompanying illustrative diagram (Fig. 6), it will be seen that the kilowatt hours may be represented by the heavily shaded area within the load curves. The lighter shaded space, including the heavy shaded area indicates the relative quantity of water used by this method to obtain the required output—whereas the very light shaded rectangular area, between the straight line drawn horizontal to the base and passing through the extreme peak, indicates the quantity of water which would be used by a deflecting nozzle only for accomplishing the same power output.

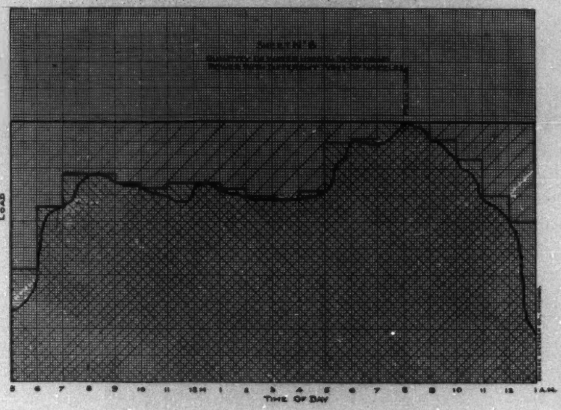

FIG. 6.

It is obvious that the best possible regulation and water economy could be effected without shock to the pipe-line if the needle is moved very slowly and follows the action of the governor, closing off some of the water whenever the governor has deflected the nozzle, or opening quickly if the governor calls for more power. The quick opening will not interfere with our pipe safety, whereas quick closing by the needle would be disastrous to a long pipe-line under high pressure. With the hand operated needle and automatic governor operated deflecting nozzle, this can only be accomplished to a limited degree, as the station attendant cannot be expected to remain at the hand wheel and

adjust the size of the stream for frequent governor changes. In some of the most recent plants being constructed we are installing an automatic device for accomplishing this result. This device depends upon the action of the governor before starting its operation and, in combination with the governor, secures the best possible regulation, pipe safety, and water economy. The

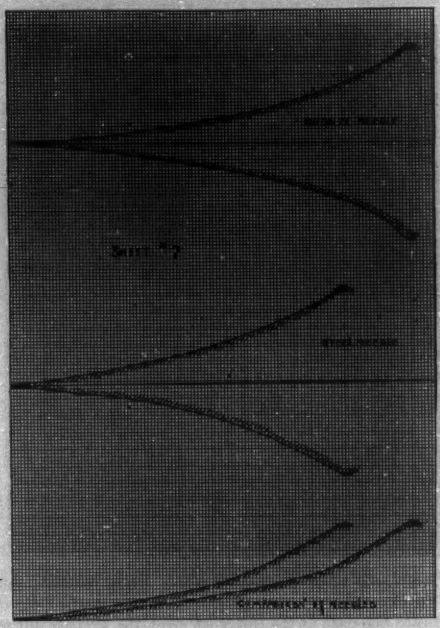

FIG. 7.

load curve and water quantity curve being almost synchronous, the quantity of water used is about proportional to the kilowatt hours' output, and exactly so if we leave out of consideration the partial load efficiency of the apparatus. These partial load efficiencies are, however, a very small item in a station employing a number of units, and the governors should be adjusted so that they follow each other in action—all but one unit being run fully

loaded, and governing being accomplished on the remaining unit. A small falling off at partial load efficiency on the unit doing the governing will then represent but an extremely small reduction in the gross efficiency in the whole station.

The needle nozzle is an extremely satisfactory device in actual operation when well designed and constructed, and the accom-

FIG. 8.—Type of tangential water wheel buckets used in the experiments; one with paint partially washed out to indicate the path of the water-jet over the surface during normal operation.

panying photograph (Fig. 12) of the jet leaving the nozzle under a pressure of 1923 ft. is interesting as being probably the first instance on record where the spouting stream under anything like so high a water pressure has been photographed.

Fig. 8 shows the series of buckets on one of the wheels, one of which the writer painted with a coat of asphaltum varnish.

After allowing it to dry for two hours, he put the wheel in operation. The wheel ran at normal load, developing about 750 k.w. for about twenty hours before being again shut down. The bucket with the paint still remaining on it is clearly shown in the photograph. The location of the remaining paint clearly shows that the water, being discharged from a properly designed and installed wheel with this type of bucket, comes from the sides of the bucket and not from the front or back.

For obtaining reliable data for use in the future design of water wheels some very careful measurements were made on the efficiency and output of these wheels and the results are appended herewith in full.

Although the plant is being used for regular service, it is to

FIG. 9.—Main weir with hook gauge measuring apparatus.

some extent in an experimental condition; as, in spite of the high efficiency obtained, some changes are being made with a view, if possible, of still further increasing this. It will be understood that the efficiencies given and exceeding 86 per cent. are the gross efficiencies of the water wheel equipment, including the losses in the gate-valve and nozzle, the windage of the wheel, and such slight losses as occur in the buckets. When we consider that the total losses of this type of water wheel apparatus summed together amount to but a little more than 13 per cent. of the theoretical energy in the water, it will be readily appreciated that the results are extremely high, and can scarcely be surpassed by any other prime mover. The thoroughly satisfactory and continuous operation obtainable from such a tangential water

wheel plant, makes it by far the most satisfactory power known for electric transmission. The maintenance and repair expenses for a plant of this character are almost negligible.

The units are separately excited from a generator driven by an independent water wheel and from a separate pipe-line, supplying only the exciter wheels during the test.

The object of the tests was to determine the efficiency of the wheel for different loads and styles of nozzle-tips.

Arrangements for Tests and Observations.

All the water delivered by the wheel under test, as well as that delivered by the exciters, was passed over a rectangular weir of

Fig. 10.—Exciter measuring weir and hook gauge measuring Apparatus. This photo also shows the still water back of the main weir.

ample capacity. The discharge from the exciter alone was passed over another rectangular weir first, hence the water used by the wheel under test was deducted from the difference of flow over the two weirs. The output of the wheel was determined by the electrical output of the generator, whose efficiency was given by the manufacturer down to half-load.

The effective head on the wheel was determined by the survey of the pipe-line corrected by the frictional drop as deduced from the dimensions of the pipe-line. This correction is so small as to

be almost negligible for the quantities used, in fact a one thousand lb. gauge located forty feet above the nozzle showed no appreciable change between the static head, and the effective head when one unit was running full power. Still the correction has been made whenever appreciable.

The large weir used for measuring the combined water of the main water wheel and exciter, was well constructed and located, though rather too wide for the quantities used. The bay above was so large as to make the velocity of approach inappreciable. The small weir for measuring the exciter water was not so well located, but as its flow was absolutely constant, it was checked by the large weir when the main wheel was shut off. Consider-

FIG. 11.—Water-wheel housings mounted on generator bedplate, hydraulic governor and connections and floor stand for controlling needle-nozzle.

able difference was observed between the measures of this latter quantity as given by the two weirs, therefore that deduced from the large weir has been adopted in the following calculations.

The output of the switchboard was measured by two wattmeters, each of which gave the whole output. One of these was an indicating wattmeter, and the other an ordinary recording instrument. The results as given by the two did not agree for all loads, being about equal at 400 k.w., above this the latter reading in excess, and below the former. The comparison of the two instruments is shown in Sheet 2. In the calculations which follow, the results given by the recording instrument have been taken, that being considered the more reliable.

The efficiency of the generator is taken as given by manufacturer as:

95.6% full-load;
95.0% three-quarter load;
92.1% half-load.

Calling the generator efficiency E, we have—

$$\text{H.P. Wheel Input} = \frac{E.H.P.}{E} - (\text{Exciter H.P.})$$

FIG. 12.—High-pressure water jet issuing from the needle-nozzle, under a head of 1923 Feet.

As the field excitation of the machine is 97 amperes, at 70 volts, about 6.8 k.w. are lost in the field, and the equation becomes:

$$\text{H.P. Wheel Input} = \frac{E.H.P.}{E} - 9.$$

Wheel efficiencies depending on switchboard instruments cannot be considered as absolute and can only show in a general way the relation between efficiencies under different conditions.

Results.

The following constants and formulæ have been used in the calculations:

Static head = 1923 feet.

Width of large weir = 8 ft. 11/64 in.

Width of small weir = 4 ft. $\frac{1}{4}$ in.

The quantity of water has been computed by Smith's formula:

$$Q = \tfrac{2}{3} c b h \sqrt{2 g h}$$
$$= \tfrac{2}{3} c b \sqrt{29 h^{\frac{1}{2}}}$$

c being taken from Smith's tables.

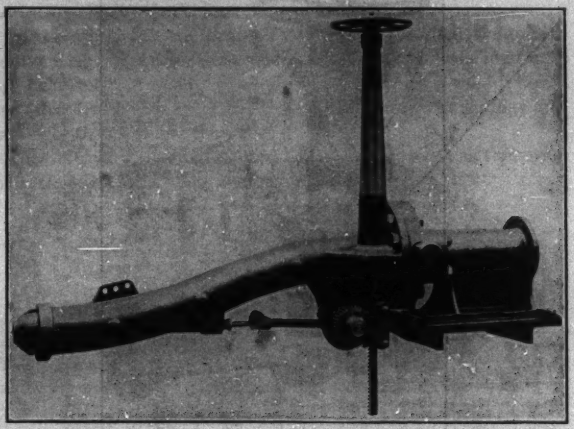

Fig 13.—Combination deflecting and needle nozzle and needle operating connections of open-hearth carbon steel castings, annealed.

The available power back of the nozzle is taken from:

H.P. = 0.1134 Q.H.

In the electrical horse-power output on the switchboard, correction has been made of 4 h.p. used to drive the blower, which was not recorded on the meters.

Three tests were made: First, a run on a 2″ tip with bronze needle; second, a run on a 2″ tip with a steel needle, and, third, a single observation on a $2\frac{1}{8}$″ tip, with a steel needle.

Since the efficiency of the generator is not known below half

load the results of the combined efficiency of the wheel and generator are given throughout the whole range.

Sheet 1 shows the curve of generator efficiency.

Sheet 2 shows the relation between the readings of the two wattmeters.

Sheet 3 shows the efficiency of the wheel to half-load for the first run, using the bronze needle.

Sheet 4 shows the efficiency of the wheel to half-load for the second run, with steel needle.

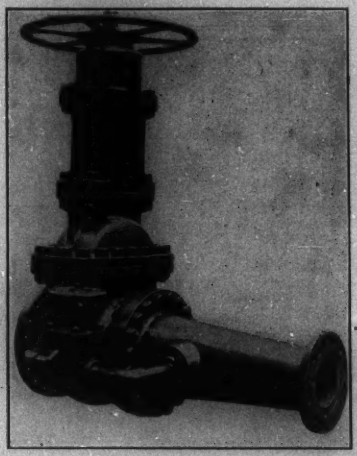

FIG. 14.—10″ Roller bearing gate-valve and connections put together with forged and turned steel bolts in reamed holes for the working pressure of 1923 Feet.

Sheet 5 shows the combined efficiency of the wheel and generator throughout the whole range, with both needles.

The difference between the results with bronze and steel needles is due to the very slight difference in curvature and not in any way to the difference in material. The results show the necessity for very careful calculation to establish the most efficient shapes of needle and tip. When once obtained the efficiency is not only higher when the parts are new but is retained, also, for a much longer time, just as would be expected; less energy being expended in eddy currents that are an invariable cause of wear.

It is to be regretted that, in taking these measurements, only commercial instruments were available. These, however, were new and in the best possible condition, and there is no reason to believe that the readings are not absolutely correct. It is unfortunate, however, that they could not have been specially calibrated for the work.

In using the recording wattmeter as a basis for efficiency determinations, it should be borne in mind that this is an instrument that has been specially manufactured for recording the kilowatt hours sold, and is therefore carefully calibrated in the factory, and probably more reliable than an instrument used for indicating the load on the machines only.

In the accompanying tables the amperes recorded are taken from one leg only of the three-phase circuit on which the load was well balanced. Any slight out of balance condition would, however, not materially affect the result as the ampere readings are used only to determine the power-factor.

The voltmeter readings should be multiplied by 7, as that was the ratio of its switchboard transformer.

FIRST TEST.
2" Tip, Bronze Needle.
Results (Hydraulic.)

Time	Weir	Weir (Feet)	C.	Total Q.	Net Q	Friction Head	Effective Head	H.H.P.
11:35	5-1/16	.422	.616	7.23	6.15	5 ft.	1918	1337
12 27	4-17/32	.3775	.618	6.12	5.04	3.5 ft.	1920	1097
1 00	4-11/32	.362	.619	5.78	4.70	3.5 ft.	1920	1024
1 20	4-3/32	.341	.621	5.285	4.205	2 ft.	1921	916
1 30	3-13/16	.318	.672	4.78	3.70	1.5 ft.	1922	807
1 45	3-11/32	.279	.625	3.945	2.885	1 ft.	1922	624
1 57	3-5/64	.256	.627	3.48	2.40	0	1923	524
2 10	2-29/32	.242	.628	3.205	2.125	0	1923	409
2 15	2-9/16	.213	.631	2.66	1.58	0	1923	345
2 20	2-17/64	.189	.634	2.23	1.15	0	1923	251
2 30	1-27/32	.1535	.640	1.65	.57	0	1923	124
3 00	1-3/8	.1145	.650	1.08	0	0	1923	0

FIRST TEST.
2″ Tip, Bronze Needle.
Results (Electrical, etc.)

Time	Indicating Wattmeter	Recording Wattmeter		Power Factor	Efficiency of Generator	Wheel Input	Efficiencies.	
		K.W.	E.H.P.				Wheel	Combined
11:35	780	(826)	(1107)	.88	95.6	1153	86.2	82.8
12:27	640	665	891	.88	95.3	931	84.9	81.2
1:00	575	593	795	1.	95.1	832	81.2	78.0
1:20	500	510	684	.98	94.4	720	78.6	75.1
1:30	425	423	567	.92	93.3	603	77.2	70.7
1:45	330	320	429	.83	90.5	474	76.0	69.4
1:57	290	269	360					69.5
2:10	260							
2:15	180	146	196					57.9
2:20	125	82	110					45.5
2:30	50	—	—					—
3:00	37.5	0	0					—

FIRST TEST.
2″ Tip, Bronze Needle.

Time	Weir	Indicating Wattmeter	Recording Wattmeter		Volts	Amperes	Speed
			Time	Rev.			
11:35	5-1/16	780	——	—	108	620	425
12:27	4-17/32	640	2 min.–10 sec.	8	108	500	432
1:00	4-11/32	575	3 " 2 "	10	108.5	450	434
1:20	4-3/32	500	3 " 32 "	10	108.5	395	—
1:30	3-13/16	425	3 " 24 "	8	108.5	350	428
1:45	3-11/32	330	2 " 49 "	5	108	295	428
1:57	3-5/64	290	3 " 21 "	5	108.5	255	—
2:10	2-29/32	260	— —	—	107.5	240	—
2:15	2-9/16	180	1 " 14 "	1	108	205	431
2:20	2-17/64	125	2 " 12 "	1	108	200	—
2:30	1-27/32	50	— —	—	108	180	228
3:00	1-3/8	37½	— —	—	—	—	—

SECOND TEST.
2″ Tip, Steel Needle.
Observations.

Time	Weir	Indicating Wattmeter	Recording Wattmeter		Volts	Amperes	Speed
			Time	Rev.			
5:10	1-25/64	375	——	—	108	0	——
5:15	2-23/32	215	2 min.–49 sec.	3	108	180	428
5:22	3-3/8	340	2 " 43 "	5	108	255	——
5:30	3-15/16	450	2 " 46 "	7	108	350	430
5:40	4-5/16	560	3 " 9 "	10	108	430	432
5:55	4-9/16	635	2 " 42 "	10	107.5	500	433
6:00	4-47/64	700	1 " 58 "	8	108.5	540	——
—	4-7/8	750	2 " 20 "	10	109	580	——
11:35	5-3/32	787	3 " 15 "	15	107	615	——

SECOND TEST.
2" Tip, Steel Needle
Results (Hydraulic.)

Time	Weir	Weir Feet	C	Total Q.	Net Q.	Friction Head	Effective Head	H.H.P.
5:10	1-25/64	.1158	.649	1.096	0	0	1923	0
5:15	2-23/32	.226	.633	2.91	1.814	0	1923	395
5:22	3-3/8	.281	.624	3.98	2.889	1	1922	630
5:30	3-15/16	.328	.621	5.00	3.904	2	1921	851
5:40	4-5/16	.359	.619	5.705	4.609	3.5	1920	1005
5:55	4-9/16	.380	.618	6.20	5.104	3.5	1920	1112
6:00	4-47/64	.394	.617	6.54	5.444	4.5	1919	1186
—	4-7/8	.406	.617	6.84	5.744	5	1918	1252
11:35	5-3/32	.424	.616	7.28	6.189	5	1918	1347

SECOND TEST.
2" Tip, Steel Needle.
Results (Electrical, etc.)

Time	Indicating Wattmeter	Recording Wattmeter		Power Factor	Generator Efficiency	Wheel Input	Efficiencies	
		K.W.	E.H.P.				Wheel	Combined
5:10	37.5	0	0	—	——	—	——	——
5:15	215	192	257	.81	——	—	——	66.0
5:22	340	331	443	.99	91.0	482	76.5	71.0
5:30	450	455	610	.99	93.8	646	75.9	72.1
5:40	560	572	767	.99	95.0	799	79.5	76.7
5:55	635	666	892	.97	95.5	940	84.5	80.6
6:00	700	732	982	.98	95.6	1022	86.1	83.1
—	750	772	1035	.98	95.6	1074	85.8	83.0
11:35	787	831	1114	.98	95.6	1156	85.8	82.6

THIRD RUN.
2½" Tip, Steel Needle
Observations.

Time	Weir	Indicating Wattmeter	Recording Wattmeter		Volts	Amperes	Speed
			Time	Rev.			
3:10	5-7/16	870	2 min.-2.5 sec.	10	108	680	430

RESULTS—(HYDRAULIC)

Time	Weir	Weir (feet)	C.	Total Q.	Net Q.	Friction Loss	Effective Head	H.H.P.
3:10	5-7/16	.453	.615	8.04	6.89	7.5	1916	1511

RESULTS—(ELECTRICAL, ETC.).

Time	Indicating Wattmeter	Recording Wattmeter		Power Factor	Generator Efficiency	Wheel Input	Efficiencies	
		K.W.	E.H.P.				Wheel	Combined
3:10	870	882	1181	.98	95.6	1230	81.4	78.2

Discussion on Paper by George J. Henry, Jr., and Joseph N. Le Conte, entitled, "An Efficient High Pressure Water Power Transmission Plant."

Mr. F. O. Blackwell:—The Redlands plant is the first three-phase power transmission plant in the United States. It had at first two 250 kw. 2500 volt generators, operated by wheels under a 300 foot head, and a seven mile transmission; synchronous motors were used. Later, a head of 800 feet was developed, and two 450 kw. 11,000 volt machines were operated on a 30-mile transmission. This plant was connected in parallel with the Santa Ana plant, which supplied a transmission line 90 miles long to Los Angeles. The plant described in the paper operates under a head of 2,000 feet and has a capacity of 4,000 h.p., using the same water as the former plant. The generators are of low-voltage, the line pressure is 33,000 volts, and feeds into the same transmission lines to Los Angeles. The Los Angeles Edison Company controls seven power stations, located at points as far apart as 100 miles—all feeding the same transmission system, and operating practically as one station; they are now developing a new plant on the Kern River, of a capacity of 20,000 hp. to operate at 60,000 volts and transmit 150 miles to Los Angeles. Thus the history of this system embodies the entire development of hydro-electric transmission in this country.

The diameter of the water wheel described in Mr. Henry's paper is 7 feet; that of the nozzle 2 inches. This ratio of 40 to 1 and the use of the needle nozzle probably account for the very high efficiency obtained—particularly at partial load. The original Redlands plant, under a 300 foot head, had an efficiency of less than 70 percent at full load and 30 percent at half load; this plant has an efficiency of 85 percent at full load and 75 percent at half load.

The regulation attained—about 2 percent—is extremely close—as good as the best steam engines. The curve of efficiency is peculiar, being high at full load, dropping off suddenly at three-quarter load, and then returning to the same efficiency at half load. The reason for this is not clear, but it is probably correct, since both tests show the same peculiarity. The water may spatter more at certain points, when the needle is thrust into the nozzle, than at others, and this may account for the lower relative efficiency at three-quarter load.

Mr. H. A. Lardner:—The pipe line of the Santa Ana plant of the Los Angeles Edison Company operates under a head of about 650 feet and is built of wrought iron pipe with flanged joints bolted together without provision for expansion. The head waters of the stream furnishing water for this and many other of the high head plants in California are in the region of perennial snow, and the temperature of the water is quite uniform throughout the year. Most of the pipe lines are buried, and on account of the uniformity in temperature of the water, no par-

ticular difficulty from expansion and contraction is experienced. Some of the pipe lines are anchored in two or three places where the condition of the rock permits, but as nearly all of them have a considerable curvature either in a vertical or horizontal plane, they are to quite an extent self-anchored when buried.

One plant in Colorado has a pressure pipe, operating under 1100 feet head, made of riveted wrought iron sections. The sections are lap-riveted together. This type of pipe has not many advocates, owing to the difficulty in making repairs.

The plant of the Standard Electric Company in California, operating under a head of 1600 feet, has a cast iron section in the pressure pipe for the upper one-third. This cast iron pipe has leaded bell joints and each bell is anchored by a concrete block which is firmly embedded into the rock of the mountain side.

The wheels employed in this plant have but one set of buckets. Some of the high head wheels, notably those of the 2000 kw. of the Standard Electric Company, have two sets of runners and nozzles in the same casing. These runners are about 14 inches apart in the Standard Company's wheels and the nozzles are so controlled that they are operated very much as the author operates two generators—one nozzle remains full on its set of buckets down to half load while between half load and full load the other nozzle is thrown on or off to meet the demand of the load. If the load is less than half, the water is entirely shut off from one of the nozzles and the governor controls the remaining one. Needle valves are not used at the Standard plant, but I should think that with large units it might be an added economy to have not only a double nozzle but the needle valve as well.

It would be interesting to know the efficiency of the needle valve in different positions, and if this varies much, the addition of the two nozzles and sets of runners would tend towards a more efficient unit.

MR. B. J. ARNOLD:—Engineers who practice in the East and Middle West have little to do with water power plants, and with them it is nearly always a question whether to use water power or put in a steam plant. Generally speaking, when the reduction of water power, due to the Winter period, is considered, it will be found desirable to put in a steam plant rather than a water plant, but this consideration does not apply to high pressure water power plants where the water supply is continuous, nor does it apply where the cost of coal is very high.

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ELECTRIC MOTORS FOR CENTRIFUGAL PUMPS AND FANS.

BY AUG. J. BOWIE, JR.

The rapidly increasing use of electric motors for driving centrifugal pumps and fans renders important the study of loads of this nature under the varying conditions encountered in practice. The possible loads which may thus be thrown on a motor, due to variations in speed, or in the head against which the pump or fan which it drives must operate, are serious enough to warrant careful consideration.

The problem of determining the proper capacity of a motor is not always easy to solve. The solution is too often the result of guesswork, and is liable to be seriously in error. In the case of direct-acting pumps working against a known head, the proper motor capacity can be easily calculated. The most economical size of motor for the purchaser, however, may not be solely determined by the possible loads, and their duration, which the motor may be called upon to carry. Particularly is this true where a flat-rate system is in vogue and where power is purchased at a price depending upon the rating of the motor and not upon the power actually used. This system of charging for power may lead to great abuse in the underrating of motors; on the other hand, it may work a great hardship on a purchaser of power who innocently uses a motor far larger than is necessary and who therefore pays for power that is not consumed. Several instances of the latter have come under the writer's observation, and in his opinion the system should be condemned. Where measurements of power are taken as a basis for determining the flat rate, such measurements should be taken under the average running conditions. A variation in these conditions may lead to a very

erroneous system of charges in the case of centrifugal pumps and fans, as will be seen later.

For centrifugal pumps and fans the power required for operation at a rated speed and head is by no means all that need be known. One should also know the maximum load which can ever come on the motor when driving the pump or fan at the rated speed and under any possible head. The maximum may be far in excess of the rating.

The problem in case of centrifugal pumps and fans will be treated under the following three heads: (1), Constant speed and varying heads; (2), Changing speed with head varying directly as the square of the speed; and (3), Constant head and varying speed.

1. Constant Speed and Varying Heads.*—The following treatment applies equally well to centrifugal pumps and to centrifugal fans, as the same laws govern the flow of air and water, but pumps alone will be considered. Represent by H the head generated by the pump. This is equal to the difference between the discharge and suction pressures plus the difference between the discharge and suction velocity heads. Represent by Q the cubic feet of water discharged per minute. The general equation expressing the relation between Q and H is, $H=A-BQ^2+CQ$, where A, B, and C are constants.

This is the equation of a parabola, and it will approximately represent the actual curves obtained in practice. Back-slippage through the running rings of the pump has not been taken into account in the above equation, and will account in part for discrepancies between theoretical and actual results.

The pressure exerted by the pump is a maximum when the first derivative of H with respect to Q, $-D_qH=0$. Hence, when $2BQ=C$, $Q=\frac{C}{2B}$, and $H=A+\frac{C^2}{4B}$, is the maximum value.

Let W_0 = output of pump in watts. $W_0=KHQ$, K being a constant. $W_0=KQ(A-BQ^2+CQ)$. This is a maximum when $D_qW=0$, or

$$A-3BQ^2+2CQ=0. \qquad Q=\frac{C}{3B}\pm\sqrt{\frac{A}{3B}+\frac{C^2}{9B^2}},$$

corresponding to $H=\frac{2}{3}A+\frac{1}{3}CQ$. In some pumps the constant C is so small that it may be disregarded. In this event the maximum head is obtained at zero discharge and is equal to A. The

*The compressibility of air is not taken into account, as the pressures at which fans are run are so light that this is a matter of small importance.

maximum output of the pump is obtained at a head of $\frac{3}{4}A$. The relative values of C and B determine the nature of the output curve of the pump and the maximum obtainable pressure. If B be fixed, the greater the value of C the greater will be the capacity of the pump. If C be fixed, the less the value of B the greater will be the pump capacity. However, the relative values of C and B will have a very important bearing on the ratio between the maximum power required to run the pump, and the power required to run it at the point of highest efficiency, or at the point of maximum output.

The quantity $\frac{C}{B}$ is influenced largely by the angle which the vanes of the pump make with the radial at the external periphery, as well as by the width of the face of the runner. However, it is beyond the scope of this paper to enter into a discussion of the design of pumps, other than in a general way, so as to show the effect of the design upon the maximum power required to drive the pump. Usually this power will increase as the effective head of the pump decreases. This would naturally be expected as long as the energy output of the pump is on the increase, but after the latter starts to decrease it might be considered natural to look for a decrease of the driving power. When B is fixed, the smaller the value of C the less will be the tendency of the pump to require additional power to drive it at heads lower than its rated capacity, and the higher the value of C the greater will this additional power become. When C is fixed, the reverse holds true for B.

A centrifugal pump, when operated at too low a head, shows a very low efficiency. In general, however, with a well-designed pump, the range of efficient operation for a constant speed is fairly broad. The principle point which the writer wishes to bring out in this connection is the danger of overloading a motor through too low a head. A manufacturer will usually guarantee a certain efficiency and input for a pump at its rated load but will say nothing concerning the power required to drive it at heads lower than that specified by the purchaser. The question may arise, why not give a pump the proper speed for a given head. This is frequently impractible, since pumps must often be installed to work under widely varying heads, where it is not an easy matter to change the speeds. Oftentimes the heads to which the water must be elevated may vary practically from zero to the maximum head against which the pump will deliver. In some cases these over-

loads may be of long duration, and a sufficiently large motor should be installed. On the other hand, the maximum load will often be only of short duration, as for example in the case of pumping from a well, particularly where there is a pit in connection with it, which is partially filled with water. Generally it will not take the pump long to lower the water considerably; and, as a rule, then, the duration of overload will be brief.

The behavior of centrifugal pumps may be represented very completely by four curves. These curves are based upon an absolutely fixed speed. Corrections for variations from this speed may be made without difficulty. These curves have, in each case, for abscissæ, the volumes of the fluids delivered in a fixed time interval; for ordinates they have respectively, head, watts input to pump, watts output from pump, and pump efficiency.

The last two curves determine the proper rating of the pump. In general, the maximum efficiency occurs before arriving at the point of maximum output. The proper rating is somewhat indefinite, as will appear from the appended curves obtained in practice. The natural tendency of a manufacturer is to rate his pumps as high as possible. Still, he does not care to go far beyond the point of maximum efficiency at the full-load rating.

The accompanying curves show the results of tests on two fans with the same casing but with different runners. In the first set $\frac{C}{B}$ is smaller than in the second set. According to the curves, the first fan is of smaller capacity, but of higher efficiency than the second. Particularly noticeable is the curve of watts input, which in the first case shows a decided concavity towards the X axis shortly after passing the maximum output of the pump. On the contrary, in the second case the corresponding curve becomes slightly convexed towards the X axis, and requires far more power under low heads. Thus the ratio of maximum outputs is 1.15, and the ratio of maximum inputs, within the range of the tests, is 1.68. These fans represent by no means extreme conditions. In the case of the second fan, if it should be called upon to operate under the lowest head tested, and if it were rated at the point of maximum efficiency and a corresponding motor were installed, then this motor would be liable to an overload of 89%.

2. CHANGING SPEED WITH HEAD VARYING DIRECTLY AS THE SQUARE OF THE SPEED.—If a centrifugal pump delivers Q cubic feet of water per minute, against a pressure of H feet while running at R revolutions per minute, and then if the speed be altered to $R_1 = KR$, it will deliver $Q_1 = KQ$ cubic feet per minute against a pressure $H_1 = K^2H$ feet. If W = watts output of pump in the first case, and I = watts input to pump, then $W_1 = K^3W$, and $I_1 = K^3I$. These equations follow from the proportionality between the head generated and the square of the speed, and because, when the volumetric output varies directly as the speed, the relative angles of motion of the water are not altered. Furthermore, all frictional losses vary as the cube of the speed,

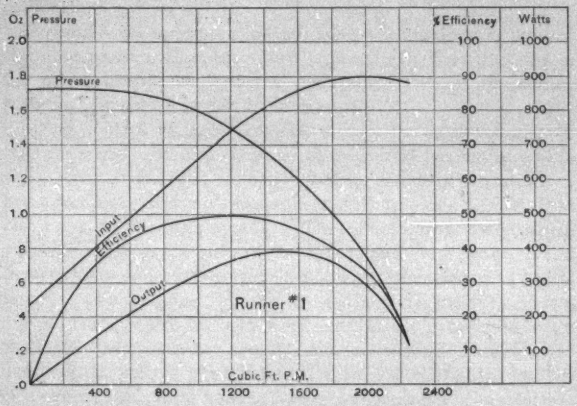

FIG. 1.

and all volumetric leakage losses vary as the speed. Hence it follows that increasing the speed of the runner, where the effective head varies as the square of the speed, will result in increasing the capacity of the pump directly as the speed, and increasing the power input and output directly as the cube of the speed. The conditions presupposed in this case; namely, that the head varies as the square of the speed, is the condition which exists in the case of ventilating fans, where the head is used up in friction in the pipe, and in the velocity-head of discharge from the pipe. This velocity-head, and also the friction head vary as the square of the discharge from the pipe.

What concerns the motor capacity particularly is the fact that the power varies directly as the cube of the speed. Hence

the $I^2 R$ loss in the armature varies as the sixth power of the speed.

3. CONSTANT HEAD AND VARYING SPEED.—This is the condition which exists when pumping against a fixed lift, when the velocity-heads lost at entrance and discharge, and when the frictional losses in the pipe may be disregarded in comparison with the lift.

In this case, and likewise in case 2, the characteristic curves of a pump under variation of speed can be obtained from those

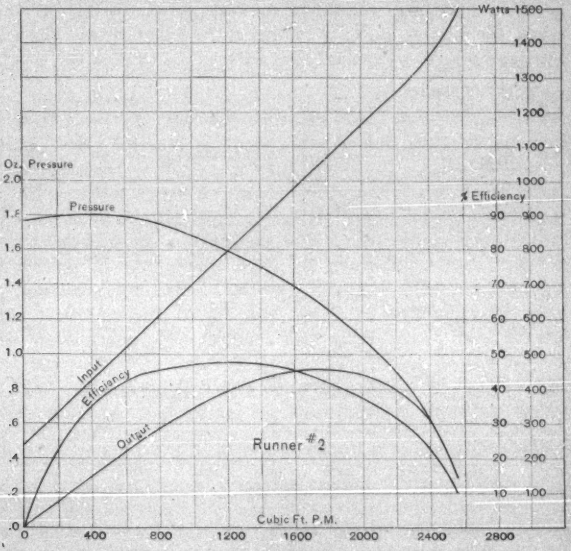

FIG. 2.

at another speed in the following manner: Let S = speed of pump at which curves are known, H = head; W_1 = watts input; W_0 = watts output; E = efficiency; rate of discharge = Q. Then if the speed be changed to $K S$, the corresponding points on the new curves for this speed will be: $K^2 H$ = head; $K^3 W$ = watts input; $K^3 W_0$ = watts output; E = efficiency; $K Q$ = rate of discharge.

It is evident that the apparatus of case 3 will operate at a point situated farther along on the curves than that of case 2; the result being a greater delivery of water, and, usually, a

greater input to the pump. In general, this input will vary faster than the cube, but not so fast as the fourth power of the speed,—as an approximation. say as the 3½th power of the speed. This makes the $I^2 R$ loss in the armature vary as the seventh power of the speed. Thus 10% increase in speed represents 40% increase in power and 96% increase in the $I^2 R$ loss in the armature. From this it may be seen what an extremely large effect speed-variation has on motors driving centrifugal apparatus. There is perhaps no other form of apparatus so sensitive to change of speed in its power consumption. The effect which a steady pump load has in holding the voltage constant by preventing the racing of generators is thus explained.

If centrifugal apparatus be provided with induction or synchronous motors, then the speed is practically fixed by that of the prime mover, so that the maximum load for the motor with a given pump or fan is determined.

Speed control of direct current motors by variation of field resistance has a limited range in practice and has many points which tend to make it objectionable for the best conditions of commutation. Even at best there will be considerable field distortion at the high speeds. The effect of a load which would increase as the cube of the speed, and even faster, would seem to limit still further the allowable speed variation to be obtained in this manner. In view of these facts it is well to provide a motor of ample size for such work, and at the same time to see that the field rheostat cannot cut in enough resistance to overload the motor. As has been shown, the volumetric output of a centrifugal pump varies directly as the speed of revolution. In spite of this fact, many manufacturers rate their pumps at a fixed volumetric output, and publish a list of suitable speeds for different heads under which it may be desired to operate the pump. In some cases the highest speed given in these lists is three or more times as great as the lowest speed. Such misinformation leads to a great deal of trouble and cannot be too strongly condemned.

In regard to the statement previously made, that the efficiencies of pumps and fans were independent of the speed, proper changes being made for head and discharge, no consideration was taken of the effect of unbalance of the runner or of bearing or stuffing-box friction. These, of course, would modify the results obtained. Lack of proper running balance is very apt to cause serious loss of power.

Discussion on Paper by August J. Bowie, Jr., Entitled "Electric Motors for Centrifugal Pumps."

Mr. H. G. Stott:—The experience of the speaker is that the variation in the power required by a centrifugal pump working under different heads, is so complex that it is impossible to make any flat rate for electric power for this service; the best method of charging is by wattmeter. As applied to barometric condensers where a variable speed is demanded, centrifugal pumps, driven by shunt wound, direct current motors, do not give good service. In starting a condenser without a vacuum, a speed at least 15 percent greater than normal speed is required; when a partial vacuum has been established, a heavy overload comes on the motor, and in all probability the circuit-breaker opens and the pump stops. When variable speed or variable head is required with a centrifugal pump, a steam engine with a throttling governor is far preferable.

Mr. F. O. Blackwell:—A particularly good feature of the reciprocating pump is that it can be operated at any speed under a constant head and will provide for a wide range of capacities. With a centrifugal pump on an ordinary supply system, if the water is not drawn off, the head increases until the pump deli ers no water; but when the water is drawn off, the pressure drops, and the pump immediately begins to deliver water A variation of perhaps 20 percent in the back pressure on a centrifugal pump will determine whether the pump will work at full capacity or deliver no water; or, conversely, a variation of only about 20 percent in speed is required between delivery of no water and full capacity; from this point of view, the centrifugal pump is ideal for electrical purposes; it also has the advantage of operating at high speed. Centrifugal pumps for very high heads, with several sets of runners, each feeding into the next, is a very promising development, and in the opinion of the speaker, will in time replace the reciprocating pump altogether. Such pumps are now made with seven or eight runners, each lifting the water 100 feet, thus giving a total lift of 700 or 800 feet, with an efficiency of 80 percent—a figure practically equal to that given by the reciprocating pump.

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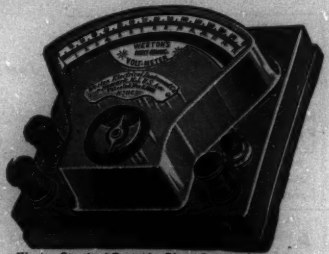

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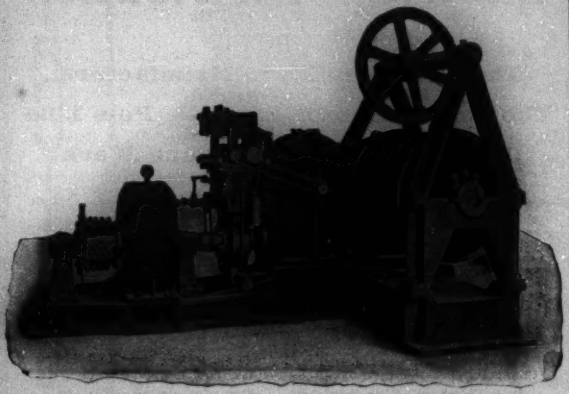

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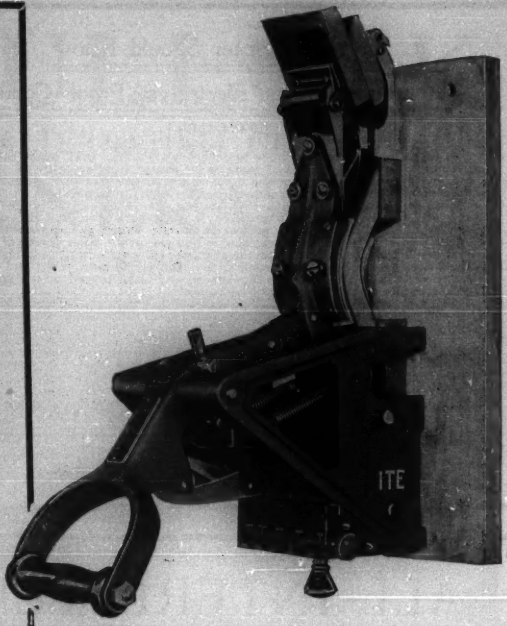

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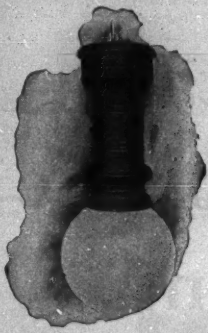

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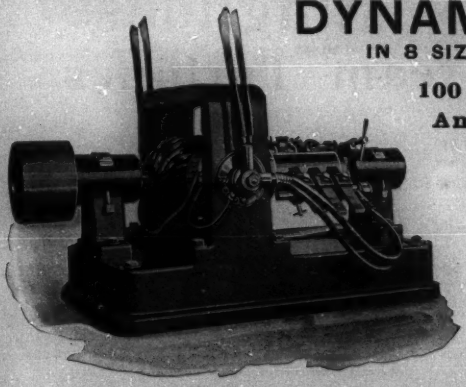

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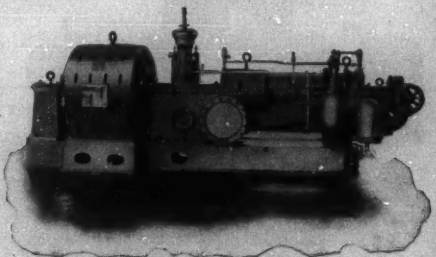

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